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THE EFFECT ON VISUAL ACUITY OF SHORTENING THE SPECTRUM AT THE BLUE END

By M. Luckiesh* and F. K. Moss**

It is well known that the optical system of the eye is not achromatic and, therefore, that images of objects illuminated by light of an extended spectral character are not as sharply defined on the retina as they are when the objects are illuminated by monochromatic light.[1] (See

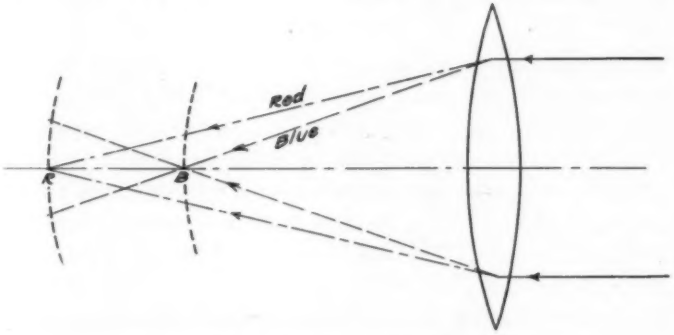

Fig. 1. *Illustrating chromatic aberration in the eye.*

Fig. 1) A number of years ago it was adequately shown[2] experimentally that visual acuity was greater for monochromatic light than for light having an extended spectrum and that visual acuity was better for

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[1] Color and Its Applications, by M. Luckiesh, D. Van Nostrand Co.
[2] Louis Bell, Elec. World, *57*, p. 1163; 1911. M. Luckiesh, Elec. World. *58*, p. 450; 1911.

monochromatic light of the wave lengths in the middle of the visible spectrum than for light of wave lengths near the ends of the spectrum.[3]

While prosecuting the work mentioned above it occurred to one of the authors that there might be some advantage in shortening the spectrum of the light from tungsten filament lamps, particularly by eliminating some of the short-wave region by means of yellowish filters. For the sake of convenience and reproducibility of the filters, various concentrations of potassium bichromate were used. The advantage looked for was apparent from this investigation, but publication of the results was delayed until such time when more observers were available. Recently this experiment has been repeated with a number of observers.

The influence of brightness on visual acuity was separated from that of the spectral character of light. The experiment was not reduced to the extreme case of comparing monochromatic light with light of extended spectrum as such a condition would seldom be practicable in practice. Previous work on this subject has indicated that an increase in visual acuity would be obtained if the blue rays were eliminated by means of filters. A quantitative study of the effect produced by the use of such a filter was made. The filters consisted of various concentrations of potassium bichromate in water.

PROCEDURE

The observer was seated in a darkened room and at a distance of three meters from the Ives-Cobb[4] test-object which was circular in shape and approximately 1-½ inches in diameter. The experimenter was located in a room adjoining that in which the observer was located and all changes in filters and brightness were made with the minimum distraction to the observer. In Fig. 2 the arrangement is indicated approximately to scale. The observer adjusted the test-object *T.O.* by rotating a hand-wheel which was belted to the pulley of the test-object. The filters were placed in a slide so that they might be changed with as little delay as possible. The light transmitted by the test-object was first diffused by passing it through two pieces of opal glass as shown in the diagram. Changes in intensity were accomplished by inserting perforated metal screens between the sheets of opal glass as shown, thereby eliminating any possible change in the color of the light with changes in intensity.

[3] M. Luckiesh, Trans. I.E.S. *7*, p. 135; 1912. Elec. World. *58*, p. 1252; 1911.

[4] H. E. Ives, Elec. World, *55*, p. 939; 1910.
P. W. Cobb, Amer. Jour. Physiol. *29*, 1911.

Three brightnesses of the background of the test-object and filter were used, namely 20.0, 2.0, and 0.2 millilamberts. These were measured through a filter of distilled water and the test-object from the side of the observer. For each background five readings were taken with each of the five filters on each day. Obviously the brightness of the background of the test-object grew less as the concentration of the colored solution used as a filter increased. In taking the readings the order in which the filters were used was varied from day to day. Data from nine observers were taken on five different days and 225 observations averaged for each of the final values.

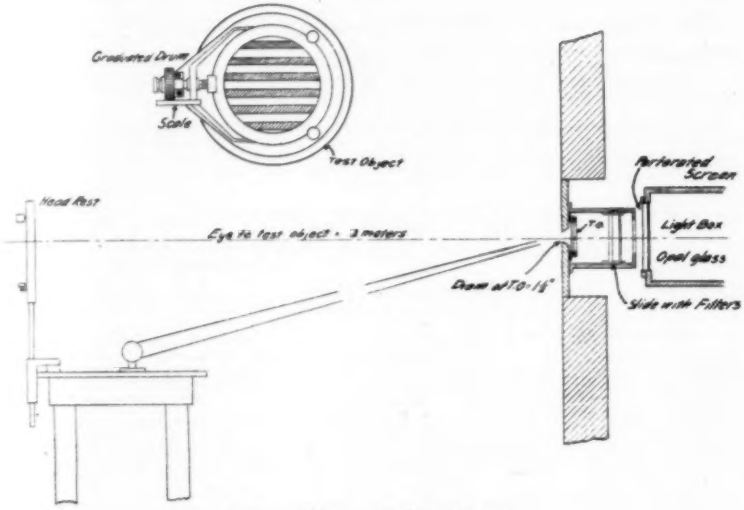

FIG. 2. *Diagram of the apparatus.*

DETAILS OF APPARATUS

The test-object[4] for measuring visual acuity consisted of two gratings (240 lines per inch) placed as close as possible to each other and mechanically arranged so that they may be rotated equally in opposite directions by means of a micrometer screw. When the lines ruled on the two plates of glass were exactly parallel the appearance of the test-object with transmitted light was that of a surface of uniform brightness. As the plates were rotated from the parallel position of the lines, dark bands were formed. The number of bands increases and the bands grow smaller as the lines diverge more and more from the parallel position. The transmission-factor of the test-object remains constant.

In Fig. 3, photomicrographs of the test-object are shown for two different positions of the lines.

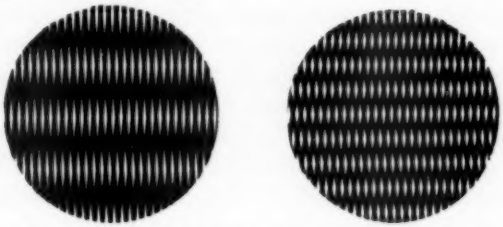

FIG. 3. *Photomicrographs illustrating the dark bands of the test-object greatly enlarged.*

The filters were rectangular glass cells containing solutions of potassium bichromate of various concentrations. A saturated solution

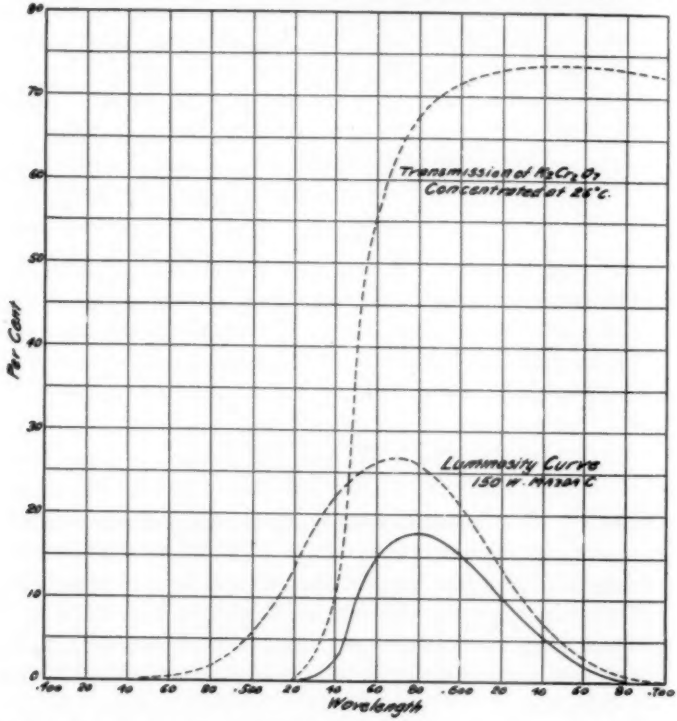

FIG. 4. *The broken lines are respectively the spectral transmission-curves of a saturated solution of potassium bichromate, and the spectral luminosity-curve of a 150-watt Mazda C lamp. The full line is the spectral luminosity-curve of the light transmitted by the saturated solution of potassium bichromate.*

(at 26° C) was made and then diluted five per cent with distilled water to prevent crystallization with changes of temperature and this solution is represented as 100% concentration. Some of this solution was diluted with distilled water to make solutions of 10%, 1%, and 0.5%, using distilled water alone for one of 0% concentration. The thickness of the solution in the cells was an eighth of an inch. The spectral-transmission curve of the filter of 100% concentration is given in Fig. 4. In the same figure is given the spectral luminosity-curve of a 150-watt Mazda C lamp and also in the unbroken line the spectral luminosity-curve of the light transmitted by the 100% filter. The spectral transmission-curves of the other concentrations can be obtained from the data in Fig. 4 by a method previously described.[1]

RESULTS

The results of the experiment are presented in the table and by the solid-line curves in Fig. 5 for the three brightnesses of background used. The values of visual acuity in the illustrations are the reciprocals of the visual angles in minutes.

Brightness of Background		20.0 *ml*		2.0 *ml*		0.2 *ml*	
Filter		Visual Angle	Acuity	Visual Angle	Acuity	Visual Angle	Acuity
Conc.	Trans.						
100%	45.7%	0.905	1.105	1.028	0.973	1.241	0.806
10	69.3	0.914	1.094	1.059	0.945	1.267	0.789
1	87.1	0.914	1.094	1.052	0.950	1.241	0.806
0.5	94.8	0.909	1.100	1.047	0.955	1.241	0.806
0	100.0	0.905	1.105	1.059	0.945	1.241	0.806

The dotted curves in Fig. 5 are those that would be expected if the acuity depended entirely upon the brightness and not upon the definition of the image as well. The curves were obtained from a curve of visual acuity (Fig. 6) plotted against brightness of background derived from all of the data. These data when plotted showed a straight-line relation between acuity and the logarithms of brightness, from which the acuity values for points intermediate between 20.0, 2.0, and 0.2 ml were interpolated.

Although the brightness of the background of the test-object when the densest filter is used is only 46 per cent of the brightness when distilled water is substituted for the yellow solution, the acuity remains

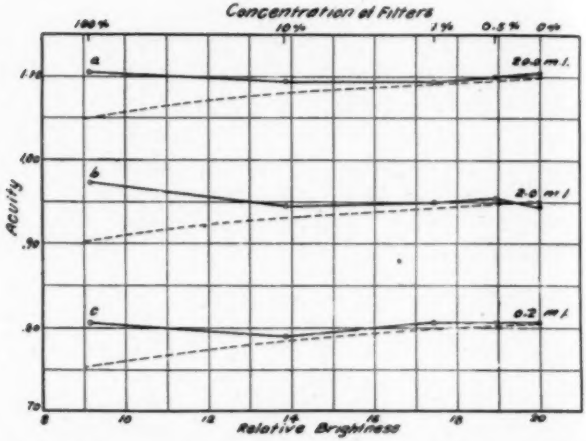

FIG. 5. *The full line a represents the visual acuity for various brightnesses of the background of the test-object as it was reduced by the filters of various concentrations, the actual brightness of the background being 20 ml. The broken line indicates how visual acuity should decrease with decreasing brightness if the influence of chromatic aberration (definition of retinal image) had remained constant. The full lines b and c are the visual acuity when the actual brightnesses of the backgrounds were 2 ml. and 0.2 ml respectively. The horizontal scale indicates the relative brightness of the background as it appeared through the various filters. The points a, b, and c represent the results when the filter was a saturated solution of potassium bichromate. The points on the extreme right of the curves are those obtained when the solution was 0% concentrated; that is, distilled water*

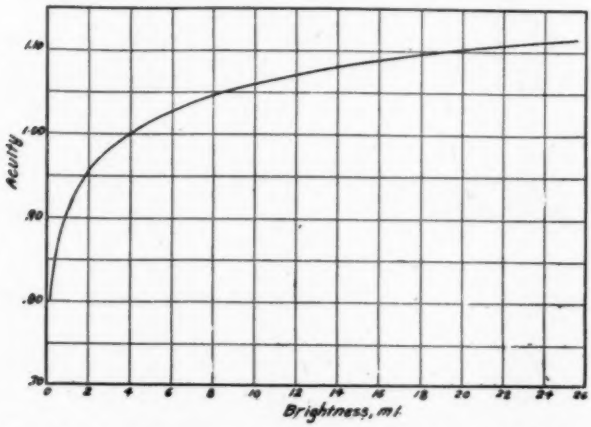

FIG. 6. *Illustrating the relation of visual acuity to the actual brightness of the background when no colored filter was used.*

about the same and even shows a tendency towards a higher value. The probable errors for the points *a*, *b*, *c* in Fig. 5 are 0.43, 0.37, and 0.41 per cent respectively. With probable errors of this magnitude, the maintenance of acuity with decreasing brightness is significant and may be ascribed to the sharper focusing obtained by the elimination of the blue rays and the consequent increase in the definition of the retinal image by reducing the influence of chromatic aberration. The gain in shortening the visible spectrum is greater than the loss due to the accompanying decrease in brightness. This accounts for some of the advantages of yellow glasses for the eyes. There are some possible applications of the use of light which has no visible radiation in the short-wave region for fine visual work. Of course, the other end of the spectrum could be eliminated but not as readily as the blue end. We have reason to believe that a corresponding gain would not result if the red end were shortened instead of the blue end.

Discharge in Gases at low Pressure.—Sir J. J. Thomson conceives that the cathode-rays depart from the cathode surface and fly completely across the cathode dark space and negative glow without ionizing the gas to any great extent; they put many of the atoms, however, into what we should call "excited" states, and these subsequently emit radiation which ionizes the gas; the negative glow is due to recombination of ions, while the cathode dark space is presumed to be dark because the strong field inhibits the recombination. Experiments show that negative glow occurs where radiations from the atoms approached by cathode-rays can reach. The field-distribution in the cathode dark space is supposed to be prescribed by the space-charge effect of the positive ions, that of the electrons being negligible because they move so fast. This theory is the same as that of Gunther-Schulze (c.f. This journal, *9*, pp. 25-26); it is generalized by Thomson to cover the case in which positive ions are produced throughout the dark space, the relation being as in the familiar case (where all the ions are supposed to start at the boundary) $voltage = constant \times (current)^{2/3} \times (distance)^{4/3}$ but with a different numerical constant. It seems however that positive ions are produced more abundantly than free electrons within the dark space, for the free electrons emerging from the dark space (cathode-rays) all have nearly the same speed corresponding to the whole P.D. across it, while the positive ions emerging from it have a wide distribution of energy. This might happen in any of several ways, e.g. by dissociation of molecules into positive and negative ions or by an atom carrying off an electron from another atom. (Thomson's proof that positive ions cannot ionize an atom by impact unless they possess a huge energy seems, however, to be based on an unnecessarily restricted conception

of the process of impact). The author considers that the expulsion of electrons from the cathode is an indirect effect of the bombardment by positive ions, due to the radiation emitted when they are neutralized as they strike the cathode. Another effect which Thomson predicts, and verifies by an appropriate experiment, is that a cathode dark space sheltered from the radiations of the negative glow should shrink more rapidly as the pressure is increased than if it were exposed to the full radiation from a widespread negative glow. In addition Thomson reports experiments on the positive-ray analysis of mixtures of gases which tend to show that in the negative glow so high a degree of dissociation prevails that a thermodynamic equilibrium exists among all the elements present and all the compounds they may form one with another irrespective of the particular chemical form in which they were first introduced into the tube. Determinations of the kinds of ions in the positive column of a discharge in air were made by drawing them out laterally with a transverse electric field and measuring e/m in a conventional way and indicated the presence of positively-charged atoms and positively-charged molecules of the gases present. An algebraic expression for the field strength in the positive column is deduced by postulating that ionization occurs either by impacts of electrons or by absorption of radiation; but is not compared with experiment.[J. J. Thomson; Phil. Mag. *48*, pp. 1-33; 1924.]

KARL DARROW

Magnetic Moments of the Atoms of Several Elements.—Extension of the important experiments of Gerlach and Stern, in which a beam of atoms, evaporated within a furnace and streaming out through a small hole in its wall and limited by an additional diaphragm, is sent across a strong magnetic field with a strong field gradient, and its deviation detected by receiving it on a plate. Modifications have been made in the apparatus which are to be described later. The beams of copper and gold atoms, like those of silver atoms, are split into two, as if each atom had a magnetic moment equal to one Bohr magneton ($eh/4\pi m$); half the atoms orient themselves one way and half the symmetrically-opposite way. The beam of lead atoms is not divided or deflected, so they seem to be non-magnetic; the beam of tin atoms is slightly widened, the beam of thallium atoms more so, as if the magnetic moment of the Tl atom were much less than one magneton (agreeing with spectroscopic theory). Bismuth yields an undeflected and one deflected beam, but not a third beam deflected in the opposite sense; which is contrary to all expectation.—[W. Gerlach and A. C. Cilliers, Frankfort; ZS. f. Phys. *26*, pp. 106-109; 1924.]

KARL K. DARROW

NINTH ANNUAL MEETING OF THE OPTICAL SOCIETY OF AMERICA

MINUTES

The Ninth annual meeting of the Optical Society of America was held in Boston on Thursday, Friday and Saturday, October 23, 24 and 25, 1924. Three sessions were held at the Massachusetts Institute of Technology, two at Harvard College and one at the Boston Museum of Art. The Society was entertained at lunch by the Institute on Thurdsay, and by friends at Harvard College on Friday.

On Thursday evening Dr. H. E. Ives gave to a large and appreciative audience in the Auditorium of the Masachusetts Institute of Technology, a very interesting lecture on The Transmission of Photographs over Telephone Lines.

A business meeting of the Society was held on Friday morning. Interim reports were received from the Treasurer, from the Chairman, Professor J. P. C. Southall, ofthe Committee on the Helmholtz Translation, and from the Journal. The substance of these reports will be published later in the several annual reports presented at the end of the fiscal year.

The Council of the Society reported that at its annual meeting, held on the preceeding day, the following items of business were transacted.

1. *Transfers to regular membership.* Seventeen members were transferred to regular membership; viz. (The numbers preceeding the names represent the serial order of election to membership in the Society.)

45. George D. Macbeth
166. Charles D. Spencer
370. Ewart S. Taylorson
399. W. F. Hamilton
400. Karl K. Darrow
401. Samuel E. Sheppard
403. Jonas B. Nathanson
404. John R. Freeman
407. John B. Johnson
409. John C. Shedd
410. Gano Dunn
411. Bergen Davis
413. Charles E. St. John
415. Arthur Pope
416. Harold W. Webb
420. Alexander E. O. Mun.ell
422. Leonard B. Loeb.

2. It was voted to accept the invitation from Cornell Universitv to hold the annual meeting for 1925 at Ithaca, during October, the exact date to be decided later.

3. *Increase in dues for regular and for life members.* After a discussion of means of increasing the Society's revenues, it was voted unanimously by the Council, two-thirds of its members being present and voting, to amend Article II, Section 1 of the By-Laws so as to read as follows:

"Section 1. Dues. Each regular individual member of the Society shall contribute seven dollars and fifty cents annually, and each individual associate member shall contribute five dollars annually, and each corporation member shall contribute fifty dollars annually toward the expenses of the Society. Any individual member, regular or associate, by the payment of one hundred dollars, may become a life member (regular or associate) of the Society." (Last sentence, relative to patrons, remains unchanged.)

Note. The effect of this amendment is to raise the annual dues for regular members from five dollar. to seven dollars and fifty cents; and the payment for life membership from fifty dollar to one hundred dollars.

4. *The Formation of Sections of the Society.* After an extended discussion of the subject, it was unanimously voted "that it is the sense of the Council that the Society encourage the formation of sections wherever the interests of the Society would be furthered thereby."

5. It was announced that the National Research Council had invited the Society to appoint a representative on the Division of Physical Sciences, and that the Council of the Society had, by vote, empowered the President, Dr. Ives, to appoint such representative. The President announced that Dr. F. E. Wright had been so appointed for a term of three years.

6. *Committee on Photographic Standards and Methods.* The Society was invited, through Dr. C. E. K. Mees, to appoint a Committee to prepare and make to the International Photographic Congress which convenes in Paris in June 1925, suitable recommendations concerning photographic standards and methods. It was moved and carried that President Ives, with other members to be appointed by him, should serve as such committee.

7. *Secretary.* Upon receipt of advice that Professor Bidwell would be unable to act as Secretary, it was voted that F. K. Richtmyer be continued as Secretary pro tem until a successor to former Secretary Priest should be elected.

8. *Secretary's Expenses to the Annual Meeting.* It was unanimously voted that the Secretary should be reimbursed for railroad fare, excluding Pullman, in attending the annual meeting.

The following addresses, papers and reports were presented during the several sessions:

ADDRESS OF WELCOME BY DR. S. W. STRATTON, PRESIDENT OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

Photochemistry, Photography and Geometrical Optics

1. S. E. Sheppard — **Eastman Kodak Company**

REPORT OF THE COMMITTEE ON PHOTOCHEMISTRY AND PHOTOGRAPHY.

2. L. A. Jones and Emery Huse — **Eastman Kodak Company**

ON THE RELATION BETWEEN TIME AND INTENSITY IN PHOTOGRAPHIC EXPOSURE, II.

This second paper on the above subject contains data of an investigation of three photographic materials, data on one of which was published in a previous paper* by the above authors. The time and intensity factors were again varied reciprocally over a range of approximately 1 to 1,000,000. The method of investigation is, in general, identical with that described in the previous paper on the subject and hence this paper consists largely of additional data. A few modifications in procedure have been found necessary and these are dealt with in detail. Among these may be mentioned the adoption of a much more satisfactory development which eliminates some of the relatively large variations found in the data previously reported. The conclusions drawn are, in general, very similar to those reached previously. The failure of the reciprocity law, while very definite and easily measurable, is not as great in magnitude as reported by other observers. It is found that the Kron formula in many cases, represents the relations between the time, intensity and density factors to within the limit of experimental error. The data are carefully analyzed from the standpoint of the Kron equation.

* On the Relation between Time and Intensity in Photographic Exposure. L. A. Jones and Emery Huse. Journal of the Optical Society of America and Review of Scientific Instruments, Dec. 1923.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received Sept. 29, 1924)

3. **Arthur C. Hardy** — **Mass. Institute of Technology**

A NEW NON-INTERMITTENT SENSITOMETER.

A rotating sector wheel sensitometer making one revolution during the exposure is probably the most satisfactory type for general use. However, if more than eight or nine power-of-two steps are used, it becomes difficult to cut the smallest steps with sufficient precision. Also, although nine steps are generally sufficient to test a given photographic material, it is necessary to provide some means of altering the speed of the wheel or the distance of the light source to accommodate materials of different sensitivity.

These difficulties have been overcome by using two sector wheels which rotate at different speeds about the same axis in practically the same plane. The small wheel rotates once each second and bears eight power-of-two steps as in the usual form of instrument. The large wheel rotates once in thirty-two seconds and has five power-of-two steps. An aperture in the large wheel allows the plate to be exposed during one revolution only of the small wheel. In this way, an exposure range from 1/256 second to 16 seconds is obtained. This range is sufficient to test both high and low speed materials and is the range of exposures ordinarily used in photographic practice. By the addition of a third wheel it would be possible to increase the range of the instrument to eighteen power-of-two steps without encountering any serious mechanical difficulties.

(Received Sept. 19, 1924)

4. **F. E. Wright** — **Geophysical Laboratory**

REPORT OF THE COMMITTEE ON GEOMETRICAL OPTICS.

5. **Hermann Kellner** — **Scientific Bureau, Bausch & Lomb Optical Company**

A NEW INSTRUMENT FOR THE OBJECTIVE DETERMINATION OF THE REFRACTION OF THE EYE.

A review is made of the various subjective and objective methods of determining the refraction of the eye. The possibilities of the different methods and the instrumental means for accomplishing their purpose are discussed and a new instrument for objective determination is described.

(Received Sept. 29, 1924)

6. **W. B. Rayton** — **Scientific Bureau, Bausch & Lomb Optical Company**

THE CHROMATIC ABERRATION OF FUSED BIFOCAL SPECTACLE LENSES.

Bifocal lenses in which the added power required to correct the eye for reading distance is gained by cementing or fusing into a depression ground into the major lens a segment of glass of higher index of refraction are generally believed to form images characterized by a high degree of chromatic aberration. The results of computation of the amount of this aberration will be given together with similar figures for unifocal lenses for comparison.

Previous efforts to achromatize the reading portions of such lenses have followed the classical theory of the achromatism of centered lenses overlooking the fact that these are not, in general, centered lenses.

The reading portion of such a bifocal can be represented by the combination of a centered lens and a prism or wedge. Achromatism results when the dispersion due to the prism is exactly neutralized by the chromatic aberration due to the lens. This can occur at only one point of the area of the reading portion, i.e., for only one direction of the line of sight.

(Received Sept. 29, 1924)

7. I. C. Gardner and J. J. Arnaud **Bureau of Standards**

IMAGE CURVATURE AS A FUNCTION OF DIAPHRAGM POSITION.

The Taylor formulas for curvature of image are used. For a combination of lenses of zero thickness it is shown that the formula reduces to a very convenient form in which the curvature is a function of the square of the distance from lens to diaphragm. Typical problems have been solved by trigonometric computation and by the modified Taylor formula in order to show the degree of agreement between the two methods of computation.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received Sept. 29, 1924)

8. G. W. Moffitt and Paul B. Taylor **Optical Laboratory, Frankford Arsenal**

AN INSTRUMENT FOR THE LABORATORY TESTING OF BINOCULAR TELESCOPES.

Devices intended for testing the adjustment of the axes of binocular telescopes have usually been designed to accommodate binoculars of approximately similar dimensions. In a laboratory where instruments of widely different sizes and forms must be studied a device capable of taking practically any binocular telescope up to 24″ in length and with entrance pupil separation up to 30″ is desirable. The new instrument fills this need without the sacrifice of features needed in the routine testing of ordinary hand binoculars.

The difference in direction of the emergent beams of light, the leaning errors and their differences, magnification and magnification difference, field of view, and quality of imagery may all be observed and judged or measured.

The instrument can be adjusted and used without recourse to distant external targets.

(Received Sept. 29, 1924)

9. G. W. Moffitt **Optical Laboratory, Frankford Arsenal**

A DIRECT SYSTEM OF DESIGN FOR THE CEMENTED TWO LENS TELESCOPE OBJECTIVE.

Attempts at simplification and more complete systematization of method and procedure in the designing of ordinary telescope objectives of this type have led to results that are of considerable interest. Useful relations that are not at all obvious from the equations of geometrical optics have been deduced empirically. Anyone having some aptitude for figures and an understanding of graphical charts can learn the method in a short time.

For any infinite series of achromats of specified equivalent focal length from any pair of glasses, the spherical aberration and the coma are shown as functions of the form, and the factors affecting the position of these curves are discussed.

Particular attention is given to the coma free type. The conditions that must be satisfied in order to obtain it are shown graphically on a chart from which one may tell, almost at a glance, whether a given pair of glasses will serve. The radius of curvature of the cemented face may also be read from a chart or from a table.

For the determination of the two remaining radii a direct method has been evolved that serves well and requires only the solution of an ordinary quadratic.

When rays are traced the lens will usually be found to be sufficiently well corrected. But if readjustment is necessary it may be done by means of the coefficients given in the paper.

It is also possible through the use of these coefficients, to make a fair estimate of the residual aberrations when the glasses that must be used do not exactly fulfil the conditions for the coma free objective.

(Received Sept. 29, 1924)

10. Dr. Paul Heymans **Mass. Institute of Technology**

PHOTOELASTICITY.

(By Invitation)

11. **L. R. Ingersoll** — **University of Wisconsin**

REPORT OF THE COMMITTEE ON PHYSICAL OPTICS.

12. **C. C. Kiess** — **Bureau of Standards**

AN ANALYSIS OF THE ARC AND SPARK SPECTRA OF CHROMIUM.

During the past two or three years the arc spectrum of Cr has been investigated for series relationships by several workers whose various published results indicate the existence of quintet and septet series systems. In the normal state of the neutral atom the series electron occupies the 1*S* term of the septet system. Above this level come other polyfold levels of which an important one is a low 5-fold *D* term of the quintet system in which originate nearly all the multiplets composed of lines of temperature classes I and II. Recent work at the Bureau of Standards has led to the discovery of additional multiple levels belonging not only to the quintet and septet systems, but also to the triplet system. Among these are 7-fold *F*, 5-fold *D*, and 3-fold *P* terms of the septet system; 5-fold *F*, and 3-fold *P* terms of the quintet system; and 3-fold *D*, 3-fold *P*, and single *S* terms of the triplet system. In the spark spectrum of Cr the multiplets represent combinations between various polyfold *P*, *D*, and *F* terms of both the quartet and the sextet systems, thus conforming to the displacement law of Kossel and Sommerfeld. The lowest level of the spark spectrum so far detected is a 5-fold *D* term of the sextet system. The multiplets so far worked out obey the selection principle for inner quantum numbers, and also the selection principle for azimuthal quantum numbers as recently modified independently by Russell and by Laporte. This work has been greatly aided by new Zeeman and temperature class observations kindly placed at my disposal in advance of publication by Mr. Babcock and Dr. King of the Mt. Wilson Observatory, to whom my thanks are due.

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Gieseler: ZS. für Physik; *22*, p. 228, 1924.

The present paper will appear in full in J.O.S.A. & R.S.I., or Sci. Papers, Bureau of Standards.
(Received Sept. 25, 1924)

13. **Paul D. Foote, W. F. Meggers and R. L. Chenault** — **Bureau of Standards**

VISIBLE RADIATION FROM SOLID TARGETS.

From theoretical considerations there is a possibility of exciting a visible or ultraviolet line spectrum by bombarding solid targets of certain metals with electrons. Copper, platinum, carbon and iron targets were bombarded by 1000-volt electrons. No characteristic line radiation was detected but general x-radiation was observed throughout the visible and ultraviolet. If the targets are heated to the point where just perceptible volatilization occurs, the resonance lines characteristic of the vapor appear. Their excitation is produced probably by the resonance scattering of the general radiation rather than by direct electronic impact.

The present paper appeared in full in J.O.S.A. & R.S.I., November 1924.

14. **Lewis E. Jewell** — **Eastman Kodak Company**

AN IMPROVED TYPE OF ILLUMINATOR FOR USE IN METALLOGRAPHIC MICROSCOPY.

The Illuminator described is compact, simple in operation, and effective, producing photographs remarkably free from field illumination color fringes, and similar defects, which are frequently produced by plain glass mirrors or prism reflectors. It can readily be adjusted so as to illuminate by either specular reflection (vertical illumination) or high power oblique illumination (similar to H. S. George's Conical Illuminator, but more simply produced) or a combination of both. It can readily be used with almost any microscope, and adjusted for

either form of illumination without material disturbance of specimen or microscopic adjustment.

The paper is illustrated with diagrams of the illuminating system and with photomicrographs made therewith.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received Sept. 29, 1924)

15. C. Matsuda — **Institute of Electrical Engineering, Kyoto Imperial University**

THE EFFECT OF VARIATION OF APPLIED VOLTAGE, CURRENT AND POWER ON THE CANDLE-POWER AND THE SPECTRAL ENERGY DISTRIBUTION OF INCANDESCENT ELECTRIC LAMPS.

It is well known that the candle-power of the incandescent electric lamp varies with the other variables, i.e., voltage, current and power, in accordance with exponential laws. In the present investigation the author studied not only the above relations for incandescent lamps of various types and sizes, vacuum and gas-filled, but also obtained empirical laws governing the mode of variation of the intensity of the spectral distribution of the lamps with the applied voltages etc. by using the Nutting Spectrophotometer.

By applying the mean numerical values of luminosity to the corresponding part of the spectral distribution of the illuminants, the author also obtained the relation between the candle-power and the intensities of the spectrum which compose the light emitted from the illuminants at varied voltages etc.

(Received Sept. 25, 1924)

Radiation and Photometry

16. Ch. Fabry — **University of Paris**

THE MEASUREMENT OF LIGHT.

At the recent meeting at Geneva of the International Commission of Illumination, a report was presented on heterochromatic photometry. Discussion followed. The aim of this paper is to give a brief account of the present status of the subject.

The most striking fact in recent developments in photometry is the great importance given to black body radiation. Most of the usual illuminants have a radiation fairly well expressed by the Planck formula; this fact affords a great simplification in the problem of heterochromatic photometry, because a single variable is sufficient to describe the energy curve. Two homochrome comparisons (one of which can be superseded by a color match) are theoretically sufficient to compare any black body radiation with a standard, and a single one if the color temperature of the illuminant is known.

The use of monochromatic comparisons is discussed and some recent results on the colored filters are given. The recently proposed methods for color matching are discussed.

Bibliography:
Recueil des travaux de la Commission internationale de l'Eclairage. 5me session. Paris 1921.
Idem, 6me session, Geneva 1924 (Reports not yet published).

Invited paper.

17. E. C. Crittenden — **Bureau of Standards**

REPORT OF THE COMMITTEE ON RADIOMETRY AND PHOTOMETRY.

18. L. Behr — **Cornell University**

A NULL METHOD PHOTOELECTRIC PHOTOMETER.

The photoelectric cell is alternately exposed to the two beams of light to be compared while the connections to the galvanometer are simultaneously reversed. The photoelectric current due to one illumination thus tends to produce a deflection in a direction opposite to

that due to the other illumination. With the aid of an auxiliary battery an additional current is sent through the galvanometer which is always opposite and approximately equal to the above two photoelectric currents. The magnitude of this additional current need not be known and it must be adjusted only roughly until the galvanometer oscillations are not annoying, a condition readily realized as the galvanometer period is about 20 seconds and the complete cycle of operations is conveniently performed in one tenth of that time. When the two illuminations are equal the photoelectric current and that due to the auxiliary battery neutralize each other and the current through the galvanometer is at all times zero. When the two beams are unequal the galvanometer deflects steadily to the right or left depending on which beam is the stronger and the amount of the deflection is proportional to the difference in strength of the two beams. This property of the arrangement adapts it to automatic operation in such a device as a recording optical pyrometer.

(Received Sept. 23, 1924)

19. Herbert E. Ives **Western Electric Company**

NOTE ON THE LEAST MECHANICAL EQUIVALENT OF LIGHT.

In this paper the value for the brightness of the black body at the melting point of platinum recently obtained by the writer is used to find a value for the least mechanical equivalent of light using the latest values for the black body constants and the melting point of platinum. The spectral luminous efficiency curve obtained by Tyndall and Gibson is employed. It is found that over the entire range of probable values of the black body constants, the values for the least mechanical equivalent of light may be plotted as a straight line in terms of $\frac{C_2}{T}$ so that the present computations may be expressed in a simple equation in which any desired values of the black body constants may be inserted. Using the latest values the least mechanical equivalent of light is found to be .00161 watts per lumen. This is practically identical with the value obtained by using the author's earlier experimental determination using the monochromatic green mercury light, when combined with the Gibson and Tyndall luminous efficiency curve.

(Received Sept. 4, 1924)

20. L. A. Jones **Eastman Kodak Company**

A NEW METHOD FOR SPECTROPHOTOMETRY.

The method described is designed to eliminate many of the errors which occur in this type of work. The exposures are continuous thus eliminating any error which might arise due to the intermittency effect. The densities compared are in all cases immediately adjacent to each other thus eliminating uncertainty arising from the variation in sensitivity over the surface of the plate used. The criterion is that of intensity equality so that exposures made to radiations of the same wave-length and of equal times and at immediately adjacent points on the photographic plate result in equal densities. The requirement that the times of exposure shall be equal serves to eliminate any possibility of error due to the failure of the reciprocity law. The photometric measurements on the developed plates consist in the determination of the points at which equality of density occur, thus avoiding the necessity of making measurements of actual densities. Preliminary results made with a trial assembly indicate that a very high order of precision can be obtained by this method.

The present paper will appear in full in J. O. S. A. and R. S. I.

(Received Sept. 29, 1924)

21. Carl W. Keuffel — **Keuffel & Esser Company**

A DIRECT READING SPECTROPHOTOMETER.

A statement of the purpose for which this spectrophotometer was developed is followed by a general description of the instrument which is known as the K & E Color Analyzer. Detailed descriptions are then given of (a) the spectrometer; (b) the photometer; (c) the light source.

The necessary adjustments are described. The precautions which must be taken in order to insure accuracy are discussed, as well as the precision of observation which can be attained.

(Received Sept. 30, 1924)

22. Edison Pettit — **Mount Wilson Observatory**

THE USE OF THE D'ARSONVAL GALVANOMETER IN RADIATION MEASUREMENTS.

The many advantages of the D'Arsonval galvanometer are commonly thought to be offset by the lack of sufficient sensitiveness for radiation work. This lack of sensitiveness is overcome by a photographic method combined with special optical devices. Galvanometers can be had which have a sensibility of 3×10^{-10} amp./mm. with 17 ohms resistance, when used at a scale distance of 8 meters. By use of a photographic registering device the deflections can be measured to 0.01 mm. which is equivalent to a Thompson galvanometer working at 3×10^{-11} amp./mm. assuming that the scale of the latter can be estimated accurately to 0.1 mm. By use of a fixed mirror in front of the galvanometer mirror the sensibility can be raised to two or three times this value.

Bibliography:
Astrophysical Journal Vol. LVI, 327, 1922.
The present paper will appear in full in J. O. S. A. and R. S. I.

(Received July 9, 1924)

23. W. W. Coblentz and C. O. Lampland — **Bureau of Standards, Lowell Observatory**

NEW MEASUREMENTS OF PLANETARY RADIATION.

The outstanding results of this investigation are as follows:

The dark part of Venus was found to emit an intense planetary radiation, amounting, per unit area, to about 10 percent of the total radiation from the bright crescent. The southern hemisphere was found hotter than the northern. If this condition is seasonal, then it will be possible to determine the position of the axis of rotation, which at present, is unknown.

Uranus does not appear to emit planetary radiation which is in accordance with astronomical data.

The measurements on Mars show that the dark regions are hotter than the bright regions; that the sunrise side of the planet is at a lower temperature than the side exposed to the afternoon sun, and that the polar regions are cold,—emitting no planetary radiation.

Three methods were used to obtain an estimate of the temperature of Mars. These measurements, which substantiate other observations, indicate temperatures ranging from 7° C for the bright regions to 22° C for the dark regions exposed under a noon-day sun.

The present paper will appear in full in Bureau of Standards Scientific Papers.

(Received Oct. 1, 1924)

24. Dr. E. R. Berry* — **General Electric Company (Lynn)**

THE DEVELOPMENT OF CLEAR FUSED QUARTZ.

(By Invitation)

* Following Dr. Berry's paper, Dr. Elihu Thomson gave a very interesting discussion on the application of fused quartz in many research fields in Optics and Astronomy.

Business Meeting:

Report from Treasurer.
Report Concerning the Helmholtz Translation.
Report from the Journal.
Report from the Council.
Miscellaneous reports and business.

Color and Color Terminology

25. Dr. Christine Ladd-Franklin — **Columbia University**

AN APPENDIX TO THE ENGLISH TRANSLATION OF THE PHYSIOLOGICAL OPTICS OF HELMHOLTZ.

Prof. Cattell, reviewing for *Science* in 1898 this work of Helmholtz, said: "It is one of the few great classics in the history of science." This judgment still holds good and the Optical Society has consequently performed a much needed service in securing its translation. The present translation may properly be looked upon as a fourth edition for it will contain important additions by both Gullstrand and v. Kries, who were two of the editors of the third edition. The contribution which I have been asked to make to this edition will consist in three parts: (1) I show that Prof. Cattell was quite right when he said, in the review above quoted from, that the *theory* of Helmholtz is so inadequate to an explanation of the facts that "if it had been proposed at the present time (1898) it would not have had a single adherent"; (2) I restore in full the work of König—the most important work yet done in color—which was very unpardonably left out of the third edition by v. Kries and Nagel; and (3) I show again the "indispensableness" of my theory to making color comprehensible.

The present paper will appear in full in L'Année Psychologique.

(Received Oct. 1, 1924)

26. Charles Bittinger — **Brookline, Mass.**

REPORT OF THE COMMITTEE ON COLOR TERMINOLOGY.

27. Irwin G. Priest, K. S. Gibson, and A. E. O. Munsell — **Bureau of Standards and Munsell Research Laboratory**

THE SPECIFICATION OF COLOR IN TERMS OF DOMINANT WAVE-LENGTH, PURITY AND BRIGHTNESS.

This paper is an extension and amplification of a paper communicated to the Cleveland Meeting, 1923, (J.O.S.A. and R.S.I. *8*, pp. 28-29; Jan. 1924). Its object is a practical investigation of this method of color specification as regards the consistency of results, in terms of the sensitivity natural to the method.

Dominant wave-lengths, purities and integral transmissions (all for a specified working standard "white light") have been experimentally determined for eight standard filters, of known spectral transmission, corresponding to eight different colors well distributed over the "color triangle." Repeated determinations of dominant wave-length by three practiced normal observers extend over a period of more than one year. Some determinations of dominant wave-length on two of the filters have been made by a few other approximately normal but less practiced observers. A few determinations of dominant wave-length have been made by two anomalous trichromats of opposite types (protanomaly and deuteranomaly). The purities and integral transmissions have been measured by three observers ("normal trichromats") for whom the visibility of energy was previously known.

Values of dominant wave-length, purity and integral transmission have been computed on the basis of previous data for the three "excitations" or "sensations" (Op. Soc. Colorimetry Com. and H. E. Ives), and the "visibility of energy," (Coblentz and Emerson; and Gibson and Tyndall).

The experimental and computed values are discussed, in terms of sensitivity, as regards:
(1) Constancy of a given observer with time;
(2) Agreement of different observers;
(3) Agreement of mean experimental and computed values.

For a statement of results and conclusions, reference must be made to the complete paper.

Bibliography:
Abney: "Colour Measurement and Mixture" (London 1891) Chap. XIII.
Troland: "Report of Colorimetry Committee—" J. O. S. A. & R. S. I.; Aug. 1922.
Ives: "Transformation of Color Mixture Equations—" J. F. I.; Jan. 1923.
Priest: "Apparatus for Determination of Color—" J. O. S. A. & R. S. I.; Jan. 1924.
The present paper will appear in full in Scientific Papers of the Bureau of Standards.

(Received Sept. 8, 1924)

28. K. S. Gibson — **Bureau of Standards**

SPECTRAL CENTROID RELATIONS FOR ARTIFICAL DAYLIGHT FILTERS.

The spectral characteristics of artificial daylight filters have been studied intermittently for several years at the Bureau of Standards. In connection with a recent test of some Macbeth daylight wedges, it was found that for a given light source, a linear relation exists between the thickness of the glass and the spectral centroid of light transmitted by it. It has also been noted, on examination of previously computed data, that for a given filter, a linear relation exists between the spectral centroids of light at various color temperatures and of the same light transmitted by the filter.

Such relations are of obvious value in the determination of either the proper thicknesses of filter or the proper color temperatures of light source to give desired color temperatures of the light through the filter. The extent to which these relations have been tested and the precision with which they hold will be illustrated.

(By the spectral centroid of light is meant the wave-length center of gravity of the luminosity curve. The relation between spectral centroid and color temperature has been thoroughly worked out at the Bureau).

Bibliography:
I. G. Priest, The Colorimetry and Photometry of Daylight and Incandescent Illuminants by the Method of Rotatory Dispersion, J. O. S. A. & R. S. I., 7, pp. 1175-1205; December, 1923.
The present paper will appear in full in Bureau of Standards Scientific Papers.

(Received Sept. 15, 1924)

29. Charles Bittinger — **Brookline, Mass.**

APPLICATIONS OF COLORS OF SIMILAR APPEARANCES BUT DIFFERENT IN SPECTRAL COMPOSITION.

The principles governing the selection of pigments and dyes which shall appear similar under one illumination and different under another. Application of such colors to changeable pictures; to theatrical effects; and to camouflage in time of war.

(Received Oct. 1, 1924)

Physiological Optics

30. L. T. Troland — **Harvard University**

REPORT OF THE COMMITTEE ON PHYSIOLOGICAL OPTICS.

31. Charles Sheard — **Mayo Foundation, Mayo Clinic**

ON THE DEVELOPMENT OF A SUBJECTIVE METHOD OF SKIASCOPY.

The paper deals with both the theory and the practice of *subjective* skiascopy (retinoscopy or skiametry), as well as with deductions drawn by the writer upon various points in physio-

logical optics. In the ordinary methods of skiascopy as practiced objectively, the operator determines the refractive error of the eye examined by observation of movements of the so-called retinal reflexes and shadows. In subjective skiametry, the person under examination becomes cognizant of the shadows cast upon the retina by means of a screen moving between a suitable light source and the eye. The directions of movement of object and image (i.e., shadow cast by object) in subjective skiascopy are the reverse of those observed by an operator or using the objective procedure and a plano mirror.

This report deals with details regarding: (1) suitable luminous objects, screens and diaphragms, (2) backgrounds and (3) forms and rates of movement of object placed between the eye and the fixation source.

The subjective method is capable of an accuracy, under repeated tests, of from 0.12 to 0.25 diopter. In the hands of the writer it has been used to investigate or determine: (1) The amount of refractive error at distances ranging from 25 feet to 1 foot. (2) A comparison of peripheral with central area refractive errors. (3) The effects of diaphragms upon the refractive corrections demanded, and the importance of the determination of the values of the peripheral refraction in distant vision and the central refraction in accommodation. (4) The variation in the astigmatic error in passing, by specified angular intervals, from the primary to the secondary refractive meridian. (5) The change in the amount of astigmatism with change in fixation distance. (6) The depth of focus and lag of accommodation in which there is present a minimum stimulus to accommodation. (8) A series of results indicating that, under the methods pursued, there is little if any stimulus to accommodation at very close fixation points. (9) The stimulus to accommodation due to longer wavelengths of the visible spectrum is greater than to the shorter wavelengths. (10) Conclusions of practical clinical value in ocular refraction are drawn from the results of the experiments.

The writer proposes to further apply these tests to: (1) a comparison of refractive findings made by visual acuity tests and subjective skiascopy, and (2) a comparison of findings by objective and subjective methods of skiascopy.

Bibliography:
Trantas, *Annales d'Oculistique*, Vol. 158, p. 458, 1921; Polock, *Annal. d'Ocul.*, Vol. 158, p. 599, 1921; Brown *Journal of Ophthal.*, Vol. 5, p. 897, 1922.
The present paper will appear in full in J. O. S. A. and R. S. I.

(Received Sept. 25, 1924)

32. **Charles Sheard** **Mayo Foundation, Mayo Clinic**

ON THE CHROMATIC ABERRATION OF THE EYE AND THE CHROMATIC VARIATIONS IN THE INTERVAL OF STURM AS DETERMINED BY A SUBJECTIVE METHOD OF SKIASCOPY.

The methods of subjective skiametry have been applied by the writer to investigations on the chromatic aberration of his own eyes and a study of the chromatic variations in the interval of Sturm. Wratten light filters were used in connection with the simple apparatus employed in the development of the writer's method of subjective skiascopy. Experimental data cover five regions, with the maximum at 4500, 5000, 5600, 6200 and 7200 Angstroms respectively. Since the writer has an astigmatic error with principal meridians vertical and horizontal, refractive corrections for both meridians in all five selected regions were obtained for distances of luminous fixation point varying from 22 feet to 1 foot respectively. The principal conclusions are:

(1) Chromatic aberration curves were obtained in agreement with results by Nutting, showing a flattening of the curve in the region of 5500-6500 Angstroms, and again in agreement with Ames and Proctor, in which little if any of this central flattening occurred. These differences in form of curve depend upon the distance of the luminous fixation object from the eye and the meridian investigated.

(2) The forms of the curves for the horizontal and vertical meridians (*i.e.*, two principal meridians) of the eye for any given fixation distance are not, in general, similar. For one or two

distances the chromatic aberration curve for the horizontal meridian is concave downward and that for the vertical meridian concave upward.

(3) Under certain conditions chromatic aberration curves were obtained which correspond to the refractive index-wavelength curve for water.

(4) For all fixation distances up to one foot, the values of the chromatic aberration of the eye for the vertical meridian (*i.e.*, principal meridian of astigmatism) exceeded those found for the horizontal meridian by a half diopter. At a distance of one foot, these values became equal or slightly reversed.

(5) Curves plotted for both the horizontal and vertical meridianal chromatic intervals show successive maxima and minima as the distance of fixation object is changed.

(6) Tests for the amount of astigmatism with luminous fixation objects of selected spectral regions show that: (1) the astigmatism is the greatest for 4700 A., (2) remains equal but of lower value in the regions 5000, 5600 and 6200 A., and (3) is the least in the region 7300 A. The chromatic variation in the amount of astigmatism in the case studied varied from 0.5 to 0.7 D.

(7) The chromatic variation in the amount of astigmatism becomes practically nil at 1 foot. A 2 mm. diaphragm used in conjunction with observations at 1 foot gives the inverted form of, or the counterpart of, the wavelength-astigmatic curve obtained at 10 to 20 feet.

(8) The pronounced effects of diaphragms upon the refractive values and the chromatic aberration curves with fixation at 1 foot emphasize the part which pupillary aperture plays in these studies.

(9) Data indicate that light and color, *per se*, as obtained by filtered spectral energy and used in the foregoing experiments, give but little stimulus to accommodative action.

(10) Data were checked through the use of any arbitrary but suitable correction placed before the eye and finding the distances at which the eye was conjugate respectively for the various luminous fixation objects and spectral regions employed.

Bibliography:

Ames and Proctor, *J. O. S. A.*, Vol. 5, p. 22, 1921; *Amer. Journal Physiol. Optics*, Vol. 4, p. 3, 1923; *Proc. Amer. Acad. of Arts and Sciences*, Vol. 58, p. 3, 1923. Nutting, *Proc. Royal Soc.*, Series A, Vol. 90, 1914. Luckiesch, *Amer. Journal of Psych.*, Vol. 29, p. 182, 1918. Helmholtz, *Treat. on Physiological Optics*, English translation, Vol. 1, p. 172, 1924.

The present paper will appear in full in J. O. S. A. & R. S. I.

(Received Sept. 25, 1924)

33. L. T. Troland and C. H. Langford **Harvard University**

THE SENSITIVITY-INTENSITY LAW FOR EQUILIBRIUM CONE MINUTHESIS.

Previous determinations of the law connecting the sensitivity of the retinal cones with the intensity of the light to which they are adapted, have been subject to errors due to the scattering of light within the eye, or due to the positive after-image process. The present writers have devised a method which is free from both of these difficulties, and have applied this method to a number of spectral stimuli. The results indicate that the equilibrium sensitivity follows a law deviating only slightly from an inverse proportionality to the stimulus intensity, with very little dependence upon wavelength. Results obtained by the new method are compared with those yielded by the two older methods, with a view to determining the magnitude of the scattered light and positive after-image processes.

(Received Sept. 30, 1924)

34. L. T. Troland and C. H. Langford **Harvard University**

THE STABILITY OF HUE UNDER CHROMATIC MINUTHESIS.

Traditional visual psychophysiology teaches that continued exposure of the retina to a chromatic stimulus results in a shift of the hue, except in the case of certain unique hues known as "invariables". In the present investigation, the writers have shown that this apparent

hue shift is specious, being due to the particular method which has been employed hitherto to demonstrate the effect. By means of new methods, it is proven that hue remains substantially constant under minuthesis (fatigue), the slight changes which occur being of an entirely different character from those reported by previous investigators. The "invariables" are characteristic of changes in stimulus intensity rather than of retinal sensitivity. In their true role, they have been carefully redetermined as a part of the present research.

(Received Sept. 30, 1924)

35. Charles Sheard **Mayo Foundation, Mayo Clinic**

INSTANTANEOUS PHOTOMICROGRAPHY OF THE CAPILLARIES IN THE LIVING HUMAN BODY.

Since the discovery in 1911 by Lombard that certain capillaries in the living human body could be rendered visible under the microscope, quantitative clinical studies of the capillaries, as to sizes and blood circulation, both in normal and abnormal conditions, have assumed much importance. Professor Krogh and others have made studies, using *transmitted* light, upon the capillaries and their circulations in transparent tissues of *Rana temporaris*. In obtaining photomicrographs of capillaries at the nail-fold, for example, *reflected* light must be used, and this has made the problem rather difficult of solution. The writer has devised ways and means for obtaining photomicrographs of the capillaries with magnifications varying from 50 to 100 in from 1/10 to 1/100 second using ordinary kodak films. The most satisfactory procedure he believes to consist in the use of an arc capable of carrying, when photographs are taken, a current of about 25 amperes, using a microscopic magnification of 50 to 75 and an exposure of 1/25 to 1/10 second. Various details as to the construction and use of apparatus and the difficulties to be overcome in the work will be discussed and a series of the original photomicrographs of the capillaries, both in normal and pathologic conditions, will be exhibited. These photomicrographic records enable quantitative data to be obtained on the skin capillaries.

Bibliography:

Lombard, *Amer. Journal of Physiology*, Vol. 29, p. 335, 1911; Krogh, *Anatomy and Physiology of the Capillaries*, 1922; Brown, *American Annals of Clin. Medicine*, Vol. 1, 1922; Krogh and Rehberg, *American Journal of Physiology*, Vol. 67, p. 153, 1924.

The present paper will appear in full in Journal of A. M. A. and Amer. Journal of Physiology.

(Received Sept. 25, 1924)

36. Charles Sheard **Mayor Foundation, Mayo Clinic**

NOTE ON THE SUBJECTIVE OBSERVATION OF THE BLOOD CORPUSCLES IN THE RETINAL CAPILLARIES.

By reason of experimentation upon the skin capillaries, the writer has become interested in finding simple methods of investigating the movements of blood corpuscles in the retinal capillaries. The literature contains several papers on this subject, including investigations by Abelsdorff, Helmholtz, Vierordt, and Rood, hence the phenomenon of the subjective visibility of corpuscles in the capillaries is not new. When looking at a dull sky, for example, observers may see indistinct faint specks which move in and then out across the field. These particles, which are blood corpuscles, must be clearly differentiated from entoptic phenomena arising from other sources, such as muscae volitantes, or floating specks as they are commonly called. By means of suitable screens, particularly a medium or dense blue-violet glass, and looking at a bright sky, these blood corpuscles (or the shadows cast by them) become visible and their movements can be observed. One may use a carbon arc focussed for parallel light and suitable screens, or may see these moving corpuscles by looking at a white matt surface illuminated by a mercury lamp. Care must be exercised in bright light sources, however, on account of the near-ultraviolet light. The phenomena observed are evidently due to white corpuscles, for the continuous stream of red corpuscles, absorbing the light, would throw a shadow of the capillaries rather than of the corpuscles themselves upon the retina. The white corpuscles, how-

ever, do not absorb blue light. Hence the shadows cast by the red corpuscles are not visible, but the white corpuscles, allowing the light to pass through, cause a discontinuity in the shadows thrown upon the retinal rods and cones. One doubtless observes, therefore, the movement of the white corpuscles in the capillaries. Various conditions, such as sneezing, bending over and straightening up, exercise, pressure on the eyeball, and so forth, exert a marked effect upon the capillary circulation. The velocities of the corpuscles can be subjectively determined by those sufficiently trained.

The present paper will appear in full in J. O. S. A. and R. S. I.

(Received Sept. 25, 1924)

37. Benjamin Ives Gilman — **Boston Museum of Art**

ADDRESS ON "MODERN SOLUTION OF THE PROBLEM OF GALLERY LIGHTING."

(By Invitation)

38. Adelbert Ames Jr. — **Dartmouth College**

THE ILLUSION OF DEPTH FROM SINGLE PICTURES.

The paper deals with the illusion of depth obtained from single pictures. It presents numerous ways by which the illusion can be increased, some of which have been described before, others as far as can be discovered are new.

The following ways are described together with their effect on our visual functions.

(1) Looking at a picture with one eye.

(2) Looking at a picture through an Iconoscope.

(3) Viewing a picture from a greater distance.

(4) Changing the convergence of the eyes from that normally required by the distance from which the picture is viewed.

(5) Looking at a picture through a small hole.

(6) Changing the accommodation of the eyes from that normally required by the distance from which the picture is viewed.

(7) Looking at a picture binocularly, with one eye receiving a sharp image, the other a blurred one.

(8) Looking at the reflection of a picture in a mirror.

(9) Looking at a picture with abnormal rotation of the visual images about the axis of vision.

The increased illusion of depth is believed to result from preventing the functioning of those depth perception faculties which tell us that all the objects depicted are on the plane of the paper thus allowing the suggestion of depth from perspective, relative sizes, form and shading to exercise an uncontradicted influence.

Bibliography:

Strieff: "Die binokulare Verflachung von Beidern, ein vielseitig bedeutsames Sehproblem." Klin. Monat. fur Augenh. LXX Page 1. 1923.

Verhoeff: "Theory of Binocular Perspective, etc." Annals of Ophthal, Apr., 1902.

MacDougall: "Perspective Illusions from the Use of Myopic Glasses," Science N. S. Vol. 9, Page 901. 1899.

(Received Sept. 26, 1924)

39. Adelbert Ames Jr. — **Dartmouth College**

PICTORIAL ART AND THE PHYSIOLOGY OF VISION.

The paper points out some of the differences between an objective scene and our subjective impression of it.

The objective scene is optically represented by its projection through a point. Such a projection of reality enters our eye at the cornea, but before it reaches consciousness it has undergone considerable alteration. These changes are due to the various modifications which

are imposed along the visual tract by the dioptic system of the eye by retinal factors, by physiological-psychological factors and finally by psychological factors.

The relation between our subjective impression of a scene and an artistic picture of it is discussed.

The paper concludes by pointing out that pictures reproducing objective reality and those reproducing illusive subjective impressions, as well as intermediate types, all have their place in the broad field of pictorial art, but that one type of picture must not be judged on the basis of standards of another.

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Vision and the Technique of Art, Proc. of Amer. Ac. of Arts and Sciences. *58*. 1, 1923.

(Received Sept. 26, 1924)

F. K. RICHTMYER
Secretary, pro tem.

Electrodeless Ring Discharge in Mercury Vapor.—Jung exposed very pure Hg vapor in a spherical glass bulb to alternating electrostatic field (damped wave trains) of frequency of the order 10^7, the maximum field strength being estimated at 30 volts/cm. The density of the vapor was varied by varying the temperature of the bulb, and Jung observed three kinds of discharge each with a particular pressure range: a diffuse green discharge at pressures 0.5 mm, a faint grayish white ring discharge between 0.5 mm and 0.12−.11 mm, and below 0.11 mm a brilliant white ring discharge. Many arc and spark lines were visible in the spectrum of the white ring, only a few arc lines in those of the two others. The current between electrodes, welded into the bulb and connected to a separate battery, decreases with increasing pressure, in the first and the third discharge; it increases with increasing pressure, in the intermediate discharge. The author remarks that the transition from the green discharge to the gray one occurs when the mean free path of an electron in the vapor is lengthened to cover a potential drop of about 9 volts at the maximum amplitude of the oscillation, and the transition from the gray to the brilliant discharge occurs when the mean free path covers 36 volts P. D., but the inferences are not very convincing.—[H. Jung, Frankfurt; Ann. d. Phys. *75*, pp. 201-211, 1924.]

KARL K. DARROW

Atom Lattices of Pd-Au and Pd-Cu Alloys.—The most interesting feature of these is that although Pd and Cu both crystallize in the same arrangement of atoms, the face-centered cubic, there is a range of Pd-Cu alloys (from 40 to 50 atomic per cent of Pd) in which a body-centred cubic lattice appears together with the face-centred one, and is almost the only one present in the 45.5 per cent alloy. The relative intensities of the beams reflected from different atom planes in this alloy indicate that the Pd atoms and the Cu atoms separately form interlocking simple-cubic lattices, with a Cu atom at the center of each cube of the Pd lattice, and vice versa. Curves of thermoelectric power, of electrical resistivity and of thermal conductivity versus composition for the same set of alloys are reproduced; they all show strikingly sharp cusps at the percentages where the body-centered cubic lattice makes

its appearance. The Pd-Au series, like the Pd-Ag series investigated by McKeehan, shows the face-centered cubic lattice everywhere with a continuously-varying spacing. The samples were prepared by melting the metals together (generally in vacuo), tempered in vacuo, annealed, cold-drawn, heated and annealed once more.—[S. Holgersson, E. Sedström, Lund; Ann. d. Phys. *75*, pp. 143-162, 1924.] KARL K. DARROW

Dependence of Diamagnetism on Pressure for three Gases.—Glaser measures the susceptibility of hydrogen, nitrogen and CO_2 over a pressure range from about 25 to about 900 mm Hg., with fields of about 4500, about 4000 and about 3000 gauss. The method gives relative values only, being the determination of the torque necessary to restore a suspended paramagnetic rod to its original orientation when the magnetic field is applied; the measurement of this torque first when the rod hangs in vacuo, second when it hangs in the gas at pressure 760 mm and third when it hangs in the gas at any other pressure p, suffices to determine the susceptibility of the gas at p in terms of its susceptibility at 760, irrespective of the magnitude or distribution of the field or the susceptibility of the rod so long as these remain constant. The strange result is that the susceptibility, accurately proportional to pressure from 900 mm down to a certain critical pressure depending on the gas and field (for the highest field it was about 600 mm for H_2, 400 mm for N_2, 300 mm for CO_2), suddenly begins to decline distinctly less rapidly with decreasing pressure when this critical point is reached. There are indications that the susceptibility varies as C_1p for low pressures, as C_2p ($C_2<C_1$) for high ones, and crosses over from one straight line to the other at intermediate pressures. The author believes that the atoms are oriented in the field at low pressures and not at high ones. —[A. Glaser, Munich; Ann. d. Phys. *75*, pp. 459-488; 1924.]

KARL K. DARROW

Excitation of the Arc Spectrum of Cs by Slow Electrons.—Attempt to determine whether each line of the arc spectrum appears suddenly when the energy of the bombarding electrons is raised just past the value of the energy difference between the normal orbit of the valence electron, and the orbit from which the valence electron falls in the emission of the line in question. Thermionic electrons from an equipotential surface of nickel probably covered by a film of caesium; contact P.D. supposed negligible because determinations of apparent ionizing potential give the correct value; space-charge supposed nearly negligible because of small current density. The results as always illustrate how difficult it is to decide whether a line appears "suddenly" or gradually; but the observations, both visual and photographic, suggest that the lines appear in the proper order at voltages 0.1 to 0.2 higher than the computed just sufficient ones.—[A. L. Hughes and C. F. Hagenow, Washington University; Phys. Rev. *24*, pp. 229-233, 1924.]

KARL K. DARROW

INSTRUMENT SECTION

METEOROLOGICAL INSTRUMENTS AND APPARATUS EMPLOYED BY THE UNITED STATES WEATHER BUREAU

By Roy N. Covert*

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* Meteorologist, United States Weather Bureau.

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INTRODUCTION

The instrumental equipment of the Weather Bureau at the present time, 1924, is the result of many years of painstaking development dating back to the beginning of the organization as a branch of the Signal Service of the Army in 1871. A few instruments such as the the Robinson cup anemometer, mercury barometer, and the maximum, minimum, and exposed thermometers, have been practically unaltered since their introduction about 1871; others from time to time have been invented, developed or adapted to the work of the Bureau by its personnel, and by cooperation with manufacturers. A brief history of each instrument or apparatus appears in the text. More complete descriptions of the equipment at present used and that employed since the organization in 1890 of the Weather Bureau as part of the Depart-

ment of Agriculture, will be found in Weather Bureau circulars, and in special articles appearing in the Monthly Weather Review. Equipment antedating 1890 is mostly described and illustrated in Reports of the Chief Signal Officer.

The magnitude of the instrumental work of the Weather Bureau is indicated by the value of the equipment in service, roughly estimated at $700000. There are nearly 200 regular stations observing practically all the meteorological elements, an additional 1600 stations forwarding special reports of temperature, rainfall, heights of rivers, snowfall, etc., and nearly 4500 cooperative stations taking observations of temperature, rainfall and general weather conditions mainly for climatological purposes.

I. TEMPERATURE-MEASURING INSTRUMENTS

1. THERMOMETERS

All the thermometers used by the bureau are stem-graduated by the maker, the freezing point found as usual by immersing the bulb and most of the column of mercury or alcohol in a bath of pure melting ice. The balance of the scale is determined by placing the thermometer in a temperature-controlled water or alcohol bath for temperatures above and below the freezing point respectively, the points of the scale being fixed by comparison with a sub-standard thermometer, the errors of which were originally found by reference to a gas thermometer or by comparison with another mercury-in-glass thermometer whose corrections were known.

Because of the large number of thermometers issued yearly, the Weather Bureau does its own testing of these instruments, corrections being found at each ten degrees of the scale above and below the freezing point. Fahrenheit thermometers are used almost generally throughout the service.

The bulbs of the thermometers used by the bureau are made of Jena glass or equivalent; the tubes of good quality lead glass. The range of graduations is varied to meet the great differences of temperature found in the several sections of the United States and its territories, which have climates ranging from tropical to polar.

(a) *Maximum thermometers*, Fig. 1A, provide a record of the highest temperature occurring at the place of exposure, from the time of setting until read. This type of maximum, developed first by Negretti and Zambra, London, England, has been employed continuously in Weather

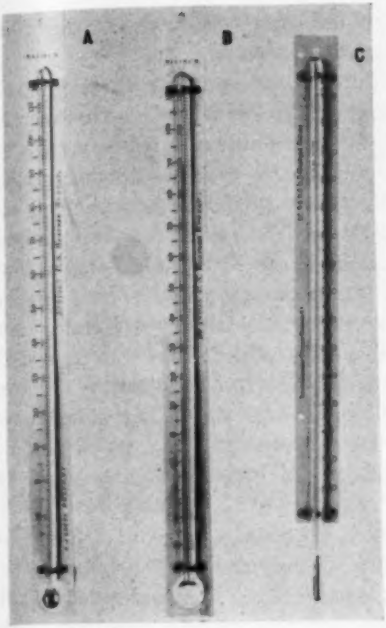


FIG. 1. *Thermometers: A, Maximum; B, minimum, spherical bulb; C, exposed.*

FIG. 2. *Minimum thermometers with cylindrical bulb and large index.*

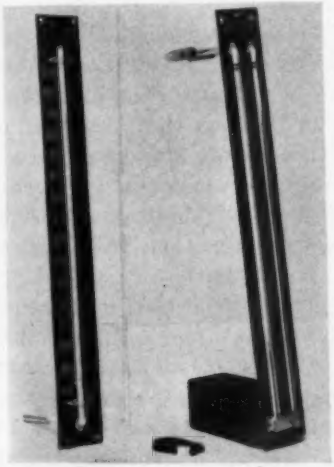


FIG. 3. *Kiosk exposed mercurial thermometers.*
FIG. 4. *Kiosk Sixe's maximum and minimum thermometers.*

Bureau work since 1871. Aluminum backs have been used for nearly 30 years; the original ones were made of brass.

The instrument differs from an ordinary mercurial thermometer in having the bore of the tube constricted near the bulb so that mercury forced above the constriction by a rise in temperature after setting can not readily return to the bulb, unless the thermometer is whirled about an axis near the upper end. Maximum thermometers are filled with pure mercury at a temperature nearly equal to the highest the given instrument can experience so that the space above the column at lower temperatures may be free of air. The maximum temperature for a given period after setting, usually 12 or 24 hours, is found by carefully lowering the thermometer bulb to a vertical position and reading on the scale the position of the top of the mercury column. Setting is accomplished by whirling in a suitable support until the column of mercury is continuous and no further whirling will force the mercury farther into the bulb, after which it is placed with the bulb slightly above the horizontal (See Fig. 80).

(b) *Minimum thermometers*, Fig. 1B, provide a record of the lowest temperature occurring at the place of exposure from the time of setting until read. They have been used practically in their present form since 1873, their construction following that of Rutherford who introduced the type in 1794, using spirit of wine instead of alcohol for the thermometric liquid.

Uncolored ethyl alcohol is used to fill the tube, which is done with the bulb immersed in a mixture having a temperature of nearly zero Fahrenheit. Air is drawn into the tube at this relatively low temperature and the tube sealed, so that at higher temperatures the entrained air exerts a pressure considerably in excess of atmospheric with the desired result that the diffusion of alcohol vapor into the air above the column and its subsequent condensation is largely prevented, thereby much increasing the accuracy of the thermometer. To provide against excessive internal air pressure at high temperatures, a small bulb is blown in the upper end of the tube.

The bore of the tube is considerably larger than that of a mercury thermometer so as to provide sufficient room for the index, a double-ended piece of dark-colored glass so shaped as to follow the movement of the upper end of the alcohol column as the temperature falls, but to remain at the lowest point when the temperature rises. As shown in Fig. 80, when in the set position the thermometer is nearly horizontal with the bulb end slightly the higher. A scale reading of the end of the

index farthest from the bulb gives the lowest temperature at the place of exposure since the instrument was last set. The setting of the thermometer is accomplished by turning it into a vertical position in the support with bulb uppermost, when the index will fall to the end of the column. The thermometer is then returned to the horizontal position first mentioned.

Fig. 2 illustrates a minimum thermometer having a large-sized index to permit of easier reading. The increased bore of the tube requires as a consequence a larger bulb, which is made cylindrical in shape.

(c) *Exposed thermometers*, Fig. 1C, are stem-graduated mercurial thermometers employed for the measurement of free air temperatures in a suitable shelter. When specially mounted for whirling, a pair of such thermometers comprises the wet and dry-bulb psychrometer described further under humidity-measuring instruments (See Fig. 41).

(c′) *Kiosk exposed thermometer*, Fig. 3, is a mercury-in-glass thermometer specially designed for use in the kiosk or street instrument shelter (See Fig. 85). The bulb end is bent at right angles to the rest of the stem to permit of its passing through a hole in a mounting plate to reach the air space in the interior of the kiosk, which space is open to the atmosphere. Otherwise it is merely a good quality stem-graduated thermometer.

(d) *Sixe's combined maximum and minimum thermometers.*—Fig. 4, specially designed for use in the kiosk and manufactured by the Taylor Instrument Companies, were introduced in 1908. They are an adaptation of the thermometer invented in 1781 by J. Sixe of Canterbury, England, and improved by Hicks of London. Thermometers of this type have a wide distribution in England and its colonies. The U. S. Weather Bureau uses them only in its kiosks, principally on account of the ease with which they may be read and set.

These thermometers as the name indicates, register both the highest and the lowest temperatures for the period since setting. Two thermometric liquids are used, one, a mixture of alcohol and creosote, the other, mercury. Referring to Fig. 4, the upper left-hand bulb is filled with the first-named liquid, while the U-shaped stem contains a continuous thread of mercury. A rise of temperature expands the liquid in the left-hand bulb and forces the mercury inward in the right-hand stem against the pressure of the vapor in the right-hand bulb. The index is pushed upward by the mercury as the temperature rises, and it remains in the highest position when the temperature falls, so that a reading of the scale with reference to the lower end of the index gives

the maximum temperature. A fall in temperature causes a reverse operation so that the mercury thread is forced toward the left-hand bulb, a second index being pushed ahead of it to remain in a position corresponding to the lowest temperature experienced, a scale reading of its lower end giving the minimum temperature since the instrument was last set. These indices are made of delicate glass tubes within which short lengths of iron wire are sealed, so that setting is accomplished by moving them with a magnet until their ends touch the mercury column. The indices maintain their position against the force of gravity by means of hair-like filaments attached to them which press lightly against the walls of the bore.

FIG. 5. *Telethermoscope*

2. TELETHERMOSCOPES

These instruments, illustrated by Fig. 5, are electrical-resistance thermometers whereby the temperatures at some selected point, usually the instrument shelter, are read from an indicator indoors. The shelter houses a bulb which consists of a coil of nearly pure nickel wire, having

a resistance of about 100 ohms at ordinary temperatures, sealed with paraffin into a nickel-plated brass tube. The coil is connected through a three-wire circuit with the indicator by means of which the changes of resistance may be measured and the corresponding temperatures indicated on a scale. Referring to the diagram, Fig. 6, the instrument is operated by first depressing the key, whereby battery current from the two dry cells flows through the line to the bulb, there to divide, one return circuit being by way of line B, fixed resistance R, helix S, fixed resistance b', and part of helix S_1 to slider V connected to the battery;

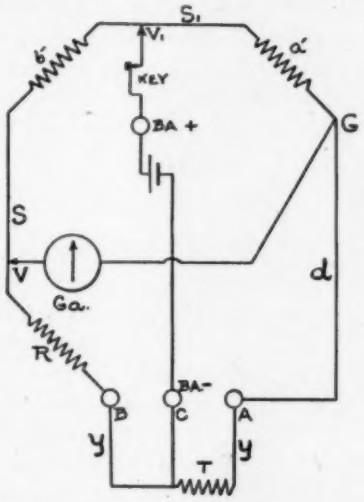


FIG. 6. *Diagram of circuits for telethermoscope.*

the other return through T (the thermometric coil), line A, fixed resistance a', and the other part of helix S_1 to slider V. The sliders are adjusted by means of the knurled knob until a balance is shown by the galvanometer, when the correct temperature is shown on the scale.

This modified form of Wheatstone bridge with contacts moving over two helices at the same time provides a means of eliminating the effect of changes in the resistance of the line wires, Y, which, however, must be equal in resistance. The resistance of helix S is made twice that of S_1, so that the sliders moving simultaneously the same distances over the two helices change their increments of resistance in the ratio of 2 to 1. The true resistance, T, of the thermometer coil and the corresponding temperature are given by the difference of resistances b and d, defined below, without regard to the line resistances, y.

Let resistance from V to V_1 be represented by a, from V to B by b, from V_1 to G by c, and G to A by d, then the equation of the Wheatstone bridge gives,

$$\frac{a}{b+y}=\frac{c}{d+y+T}$$

But by means of the above-mentioned arrangement whereby $\lambda S = 2\lambda S_1$, and a is maintained equal to c, the equation reduces to

$$b+y=d+y+T, \text{ or } T=b-d$$

Two other types of telethermoscopes in present use were brought into service previously to the one described, beginning in 1908, one operated as a simple Wheatstone's bridge, the other on the differential galvanometer principle. All of them have been made to order by the Leeds and Northrup Co., Philadelphia, who developed the instrument in cooperation with Prof. C. F. Marvin.

3. THERMOGRAPHS

(a) BOURDON-TUBE TYPE

(1) *Richard thermographs*, and thermographs in general, are used to give a continuous record of the free air temperature during a desired period, usually seven days. The bourdon-tube thermograph was invented by Jules Richard, France, about 1880 and introduced into the Weather Bureau in 1886. There has been no essential alteration in the construction since its invention. Three types are in current use differing mainly in the range of temperature allowed for on the record sheet. The so-called intermediate thermograph is illustrated in Fig. 7. Provision is also occasionally made to open up the time scale by causing the clock cylinder to revolve once in 29 hours.

The bourdon tube itself (1) Fig. 7, is elliptical in cross-section with axes 1/8″ and 1 11/32″, and walls of No. 29 gage (.011) phosphor-bronze. The tube is bent into an arc of nearly 2″ radius. It is silver plated and polished, carefully soldered to a triangular shaped bar (2) at one end, and to a header (3) containing a short piece of lead tubing at the other. Through this tubing pure grain alcohol is introduced and sealed off under pressure. The triangular bar is pivoted to the bracket (4) attached to the frame; the header carries a rod (5) connected to the linkage (9) actuating the pen-arm. Screw (6) is operated to adjust the pen to the current temperature by turning the pivoted end of the bulb by means of the attached arm (7) held in place by the compression spring (8) encircling the screw. The linkage also permits of an adjust-

ment of the range. The pen arm (10) is made of thin spring brass or aluminum, the pressure of the pen on the record sheet being adjusted by a thumb screw (11) near the fulcrum. The cylinder (12) is driven by an 8-day clock within.

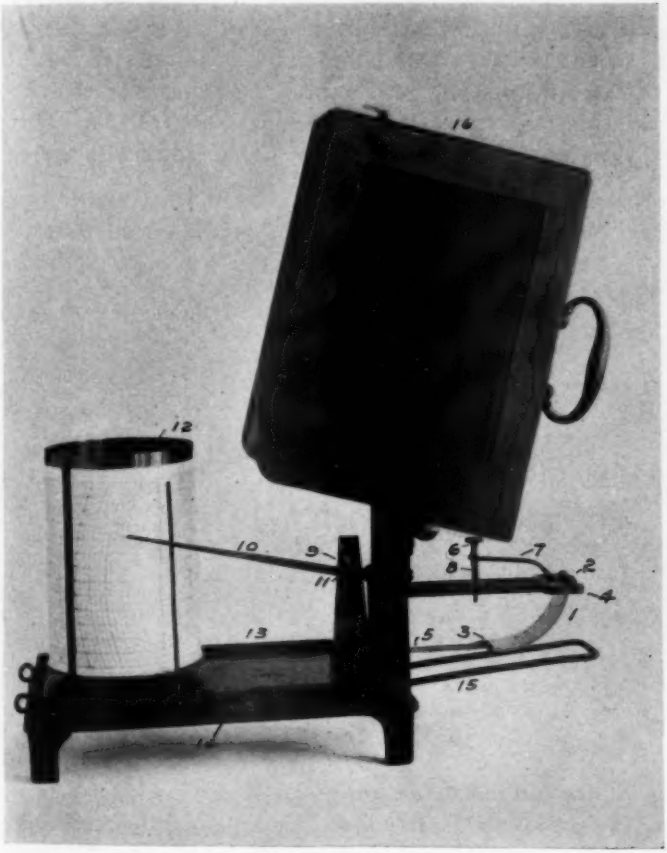


FIG. 7. *Thermograph, intermediate type.*

A rising temperature causes the alcohol in the bulb to expand, resulting in an outward pressure of the alcohol which in turn reduces the curvature of the bulb and moves the linkage bar at the left-hand end

of the bulb downward and to the left with a corresponding rise of the pen on the record sheet. Records are corrected to agree with the twice-daily observations of the thermometers, and the exact time of observation is marked on the record by displacing the linkage rod slightly, thus causing the pen to trace a short vertical line.

2. *Kiosk thermograph*, Fig. 8, is a form of bourdon-tube thermograph adapted to particular conditions of exposure. It was designed by Prof. C. F. Marvin in 1908. The bulb is identical with that used in the Richard instrument, but its mounting requires different linkage and adjustments, as are evident in the illustration. Range adjustment is provided at (7), the position of the pen to agree with the current

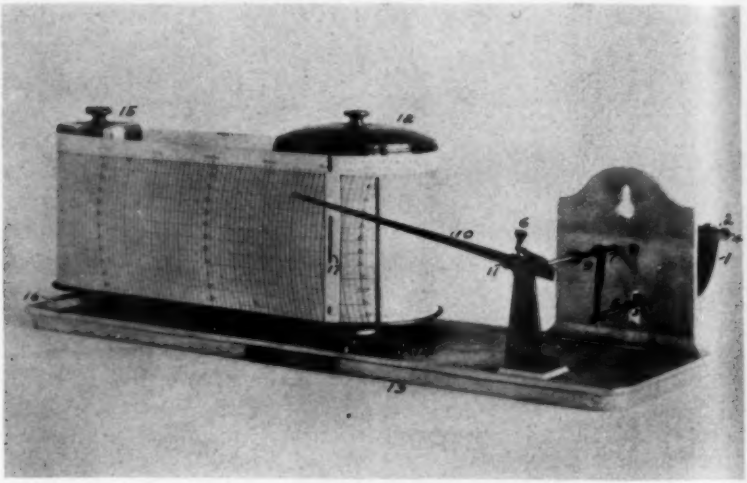


FIG. 8. *Kiosk thermograph.*

temperatures is made at (6). Provision is also made for a two-week record instead of one, the sheet being passed around a second cylinder, (15), which is mounted on a lever arm (16) with a spring to keep the paper under tension. The ends of the record sheet are linked together at (17) with a flat phosphor-bronze pin.

(b) *Bi-metallic thermographs*, of the Short and Mason type, Fig. 9, have been used to a limited extent by the Bureau since 1907. Historically, a thermograph employing a thermometric element made of a

compound bar bent into the form of a letter C and opening out or closing with variations of temperature, was invented and built by N. S. Heineken in England in 1837. Others were also made by Hipp, Hottinger, Wild-Hassler, Draper, and Richard. A spiral strip of steel and brass was employed in the Wild-Hassler instrument. Since the introduction of invar, bimetallic strips combining this metal with bronze have come into use, those recently made having the two metals electrically welded together. The invar-bronze strips are not so easily corroded as the steel-brass, and the ratio of the coefficients of expansion of the metals in the former is nearly nine times as great as in the latter.

Referring to Fig. 9, (3) is the bimetallic strip made into a helical coil, one end adjustably attached to the frame of the instrument, the other end so arranged as to directly produce a rotary motion of the pen

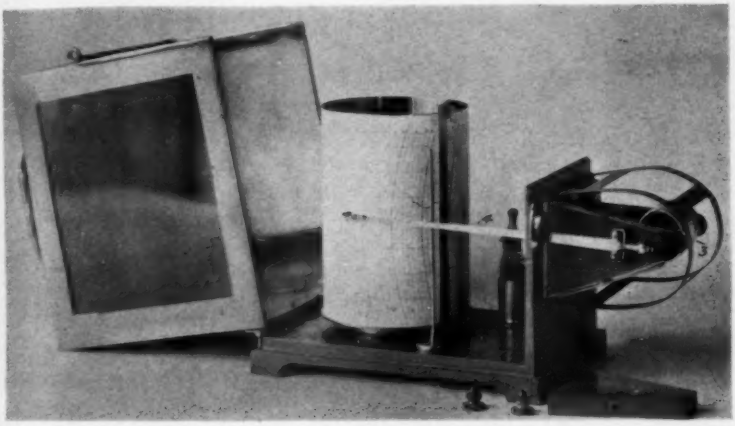


FIG. 9. *Bimetallic thermograph.*

spindle, which passes longitudinally through the axis of the coil. A casting attached to the frame contains bearings for the spindle. Range adjustment is effected at the pen end of the coil with a clamp by which more or less of the total length of the bimetallic strip is included in the coil proper, thus increasing or decreasing the total sweep of the pen across the record for a given temperature change. The frame attachment provides an adjustment to set the pen to the current temperature. The pen arm (4) is ingeniously set in pivots at the spindle end in such manner as to produce the proper pressure of the pen on the record sheet

by means of gravity, thus dispensing with the customary screw adjustment.

(c) *Distance-recording thermographs*, of the type shown in Fig. 10, were designed by Julien P. Friez and Sons, Baltimore, Md., and introduced into the bureau in 1922. The thermometric bulb consists of a group of copper tubes filled with a non-freezing liquid, united by headers at each end, and connected through a capillary copper tube, not more than 75 feet long, with the recording mechanism. The latter consists mainly of an element whose movement is proportional to

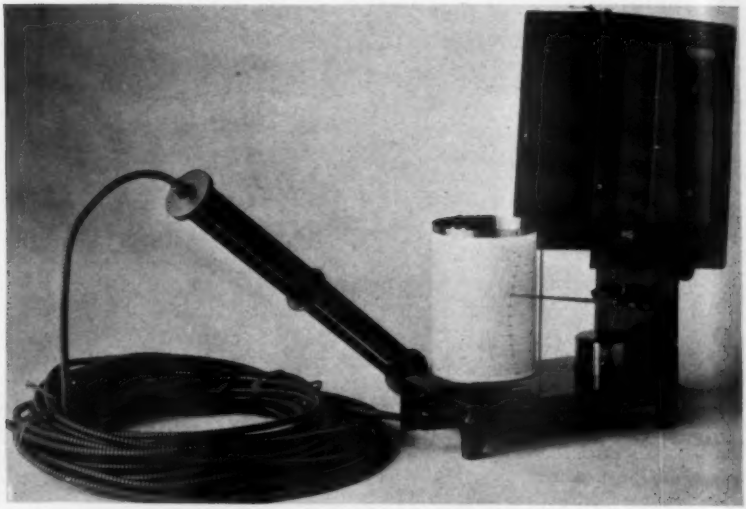


FIG. 10 *Distance-recording thermograph, pressure type.*

changes in pressure transmitted through the capillary tube from the bulb exposed to variations in temperature. Motion of the pressure element of the recorder is magnified and transmitted to the pen by means of the usual system of linkage with adjustments. Compensation is made in the recorder for changes in hydrostratic pressure due to variations in the elevation of the bulb above the recorder.

II. PRESSURE-MEASURING INSTRUMENTS

Since the forecast of coming weather changes is primarily based upon the prospective movements and changes in intensity of areas of high

and low atmospheric pressure, it is apparent that the accurate measurement of this pressure is a fundamental requirement. Each of the first-class stations of the bureau is therefore equipped with two reliable mercury barometers, and certain of the more important stations have a sub-standard barometer in addition, all of the Fortin construction.

Barometers received from the maker or repaired ones are carefully compared at the Central Office with an Adie sub-standard and the correction for instrumental error determined. This correction, usually not more than .010 in., includes corrections for scale error, capillarity, and an imperfect vacuum of small magnitude. In the hands of an expert any considerable departure from a good vacuum is found by slowly inclining the barometer from its normal vertical position until the mercury strikes the top of the tube a slight blow. If there is a sharp click the vacuum is sufficiently good; a dull sound is evidence of the cushioning effect of the air or vapor present. Tubes found with imperfect vacuums are of course refilled. When determining instrumental errors, the total correction is modified to allow for the departure of the temperature of the scale from the standard, 62 deg. Fahrenheit. True measurements of the barometric height at the place where the barometer is read require additional corrections for local gravity, and the temperature of mercury and scale, the standard mercury temperature being 32 deg. Fahrenheit.

Continued accuracy of the barometers in service is secured through monthly comparative readings of the station and extra barometers, and by occasional examinations and cleanings by inspectors, who usually carry with them for use in making comparisons a portable barometer recently corrected to agree with a sub-standard. Lack of progressive changes in the differences between the monthly readings of the station and extra barometers indicates as a rule their continued good condition.

In addition to the mercury barometers, many first-class stations are furnished with an aneroid barograph. Aneroid barometers are employed almost exclusively in marine work in securing cooperative observations of atmospheric pressure at sea, which with the advent of radio, has become of much importance from the forecast standpoint in increasing the area from which daily observations are received. Aneroids are also displayed in the street instrument shelters, while aneroid barograph mechanisms form a part of the kite and balloon meteorographs. (See pages 401, 386 and 389).

1. MERCURY BAROMETERS

(a) *Adie sub-standard barometers*, Fig. 11, a number of which were constructed in London and purchased from 1877 to 1888, are now used to determine the instrumental errors of barometers issued for station observations of atmospheric pressure. These sub-standards were carefully compared with the normal barometer at Kew Observatory, England, before shipment to the United States and the continuity of their corrections has since been determined by periodic comparative readings amongst themselves. The liberal dimensions of tube and cistern largely reduce possible errors due to capillarity. The construction is simple and rugged and the mounting secure against accidental movement. Referring to the figure: the thin brass tube (1) encloses the glass tube (2). The latter is about 1/2 inch in diameter and is visible at the top of the instrument where the brass is cut away. (3) is the cistern; (4) the thumb screw for raising and lowering the mercury in the cistern to contact with the ivory point; (5) the scale, usually graduated in inches and twentieths; (6) the vernier, moved up and down by rack and pinion, the latter turned by the knurled head, (7); (8) is the attached thermometer. The instrument is strongly supported by brackets (9) and 10 attached to the back of the case. Adjustment of the tube to the vertical is made at the top, the bracket (10) carrying a ring with three clamping screws which engage the upper end of the instrument.

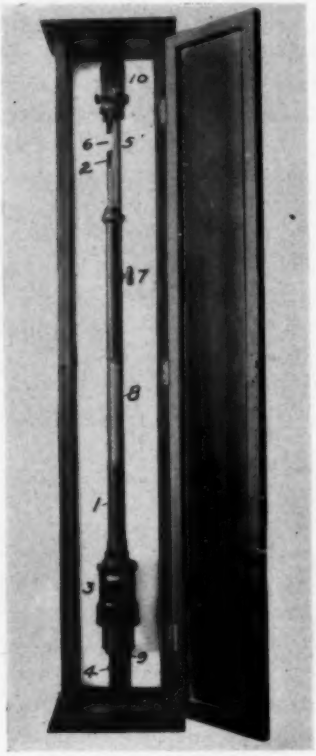


FIG. 11 *Adie sub-standard barometer.*

One advantageous feature of this barometer not seen in the picture is an air trap part way up the glass tube, so constructed that should small quantities of air by some means find their way into the tube, they would be prevented from reaching the vacuum space above the top of the column.

At the lower end of the barometer there is engraved the following:

"For comparisons of barometers for international simultaneous meteorological reports."

(b) *Station barometers*, so-called, Fig. 12 (a), are employed in the bureau for daily observations of atmospheric pressure. These barometers, of the type first suggested by Fortin in 1810, were introduced into the bureau in 1871, and their construction has been subject to but little change since.

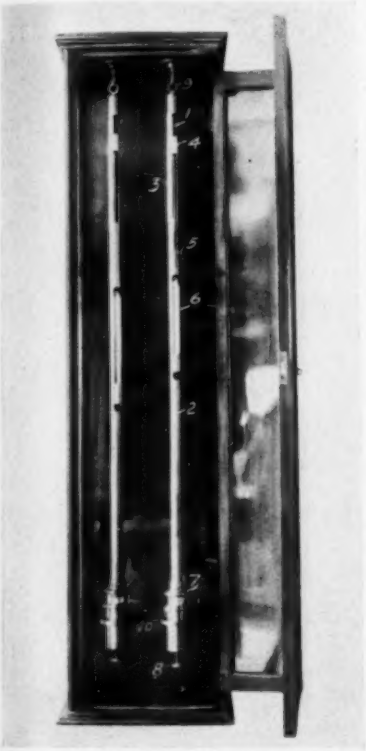


FIG. 12 (a) *Station barometer, Fortin cistern.*

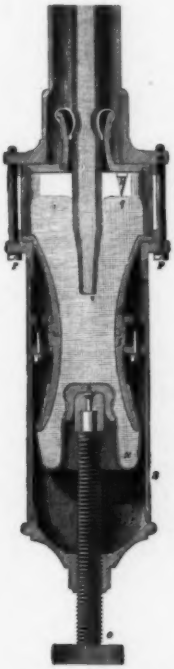


FIG. 12 (b) *Details of barometer cistern.*

Referring to the figure: (1) is the glass tube having an inside diameter of nearly 1/4-inch. This is inclosed in a thin brass tube, (2), having large openings on opposite sides near the top through which the height of the mercury in the tube within is measured on the scale, (3), and by the vernier, (4), to the nearest thousandth of an inch. The vernier (4)

is attached to a second tube free to slide within tube (2), the motion being produced by a rack and pinion, the knurled head of the latter being seen at (5). The attached thermometer, (6), has its bulb placed between the metal case and the barometer tube proper, so as to indicate approximately the mean temperature of case and mercury. The cistern (7) is of the Fortin type, the special feature being the manner of adjustment of the mercury to the fixed ivory point forming the zero of the scale. The raising and lowering of the mercury is accomplished by means of the screw, (8), the inner or upper end of which acts on the kid-leather bag forming the bottom of the cistern proper. Details of the cistern are shown in Fig. 12 (b). Air passes into it through the flexible leather joint between the upper boxwood portion and the glass tube. The brass ring (9) Fig. 12 (a) engages a hook whereby the instrument is suspended from the top of the box used to house the barometers. Verticality of the barometer is secured by allowing it to come to rest under gravity when suspended from the hook and then clamping the cistern end by means of the three screws in ring (10) attached to the back of the box.

Cisterns of a different construction will be found in a considerable number of station barometers. In these the raising and lowering of the mercury is accomplished by a piston forming the bottom of the cistern, the piston being moved by means of the usual milled-head screw. The cistern is provided with an air vent.

The barometers above described are those which are in active service. The Bureau has also a considerable number of fixed-cistern barometers of the Kew pattern which were originally used in marine work. Aneroids, however, have almost entirely displaced them. Feuss siphon barometers with adjustable cisterns and others are also included in stock but seldom used.

2. ANEROID BAROMETERS

(a) *Marine or Kiosk barometers.* Aneroid barometers, of the type shown in Fig. 13 (a) and (b), and all well made aneroids, indicate the barometric pressure where exposed and are particularly useful in measuring changes of pressure. They are mainly employed in the current work of the bureau to secure observations aboard ships at sea, although some of them are also displayed in kiosks. Fourteen other kinds of aneroids furnish an interesting exhibit from the historical standpoint. All of them utilize the expansion or contraction of a corrugated metal shell with a balancing spring, either within or without the shell, as the pressure element, and all but one indicate the pressure by means of a hand moving over a dial, the motion being communicated to the dial

FIG. 13 (a) *Marine or kiosk aneroid barometer.*

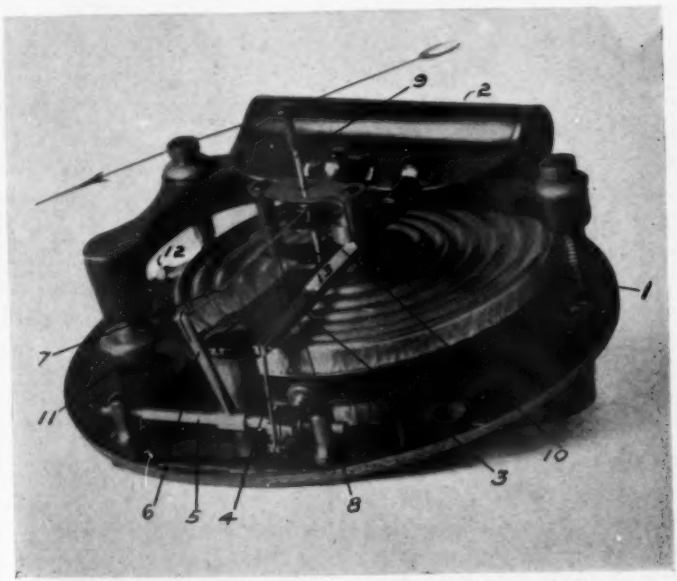


FIG. 13 (b) *Case of aneroid removed to show details of mechanism.*

pointer by a suitable linkage including a small flexible metal chain. In one, however, the Goldschmidt aneroid, the reading is made by means of a microscope and a micrometer screw.

The first aneroid is said to have been built by Vidi in 1843, and many improved forms have followed. Those illustrated in Fig. 13 have been purchased from time to time since 1909 and were made by Short and Mason, London. The type was first originated in France by Nandet. The dials are 5½ in. in diameter, the case of brass, and the 26-31 inch scale graduated to .02-inch subdivisions. Others are scaled with different ranges, e.g., 24 to 31 inches, and 20 to 31 inches.

Fig. 13 (b) shows the mechanism in detail. (1) is the corrugated aneroid shell made of thin german silver, the diameter 2 13/16 inches and the thickness about 1/4 inch at the periphery. Steel spring (2), coupled by a knife-edge to the stud on the shell, balances the air pressure tending to collapse the shell. Variations of air pressure cause corresponding movements of the shell along its vertical axis, and the upper side of the D spring with the attached compound bar (3) moves with it. Link (4) changes the linear motion of (3) to the rotary motion of the pivoted spindle (5). Lever arm (6) rotates with the spindle and at its outer end is a loose link (7) joined to the fine brass chain (8). This latter produces in turn the rotation of the pen axis (9), the chain attached to and passing around a small arbor firmly secured to the axis. (10) is a light helical spring which keeps the chain and linkage taut. Adjustment of the pressure to agree with a mercury barometer is accomplished at (11), a screw reached through the back of the case and the mounting plate operating to move spring (2) and its support. The vacuum shell is exhausted through the tube at (12) which is then closed by pinching and sealing with solder. At (13) is a piece of steel about 1/2 inch long and 1/32 by 1/8 inch in section brazed to the brass of bar (3). This bimetallic arrangement provides compensation for the instrument over a considerable range of temperature, the flexure of the bar being such as to nearly offset the temperature effect on the spring and shell and the connected linkage.

The aneroid above described is expected to meet among others the following specifications:

Temperature compensation,—At constant pressure, readings shall not change by more than 0.015 inch for a temperature change of 50 degrees Fahrenheit.

Friction,—Deviations due to friction should not exceed 0.03 inch.

Tests,—

(1) With pressure increasing at the rate of 1 inch in 5 minutes, the instrument will be tested at atmospheric pressure, 30.0 and 30.5 inches. The correction at any point in this test must not differ from that at 29.5″ by more than 0.04 inch.

(2) With pressure diminishing at the rate of 1 inch in 5 minutes, the instrument will be tested at atmospheric pressure, 29.0, 28.5, 28.0 and 27.5 inches. The correction at any point in this test must not differ from that at 29.5 inch by more than 0.04 inch.

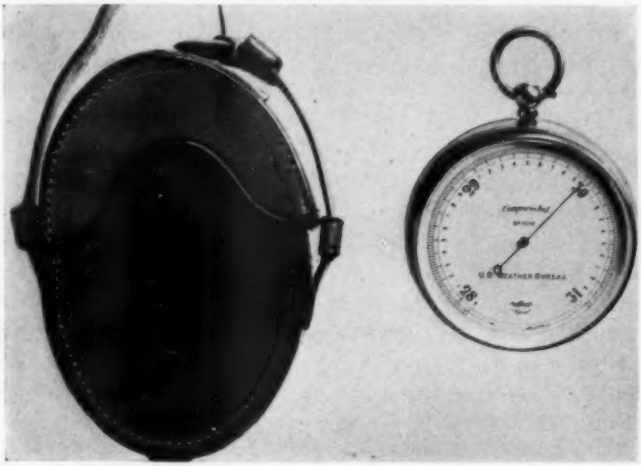


FIG. 14 *Pocket aneroid barometer.*

(3) The pressure will be held stationary at 27.5 inch for about 5 minutes, after which it will be increased at the rate of 1 inch in 5 minutes; and with rising pressure corrections will be determined at 27.5, 28.0, 28.5, and 29.0 inch, and atmospheric pressure. The corrections so determined must agree with the corrections determined under (2) within 0.06 inch.

(b) *Pocket aneroid barometers,*—Fig. 14, are of Short and Mason manufacture, and were procured for use in altitude measurements. The dials are 2½ inches in diameter, the scales with various graduations depending upon the range of altitude through which the barometer would be carried. Some of them are scaled as low as 14 inches; all of them read to 31 inches. A few of the instruments have an altitude scale with a stem-winding altitude adjustment. The mechanism is similar in construction to the aneroid first described.

3. BAROGRAPHS

(a) *Richard aneroid barographs*, Fig. 15 (a), are used almost universally throughout the bureau for obtaining records of atmospheric pressure. Like aneroids, they are secondary instruments, the continued accuracy of which is found by periodic comparisons with the mercury barometer.

The Richard barograph was invented by Jules Richard, Paris, France, in 1880, and introduced into the Weather Bureau in 1888. Its present construction does not differ in any essential from the original instrument.

Referring to Fig. 15 (a), (1), the pressure element consists of eight aneroid shells so joined as to act as a unit with nearly eight times the displacement of a single shell, the lowest of the eight being adjustably attached to the base plate (2). Each shell contains a steel spring which balances the atmospheric pressure when the shell is exhausted. The stem (3) attached to the upper shell moves up and down with changes in pressure, its motion being transmitted to the recording pen (4) through the pivoted lever, (5), link (6), and bell crank (7) attached to pivoted spindle (8) to which the pen arm is also rigidly fixed. Adjustment of the pen pressure on the record sheet is made by the thumb screw (9). The pen may be lifted from the record sheet by means of bar (10) moved by a lever (11) projecting through the case. Temperature compensation is secured by leaving a suitable quantity of air in one of the shells. The change of pressure of this air with temperature sufficiently offsets the temperature effect on the shells and linkage, such as ordinarily occurs for an indoor exposure of the barograph. The screw adjustment of the bottom shell to the base provides a means of setting the pen to the current pressure. Lever (5) carries a weight near the right hand end which takes up the back lash in the linkage. Record cylinder (12) is driven by an 8-day clock within, and the seven-day records secured are corrected for pressure and time to agree with the twice-daily observations of the mercurial barometer.

(b) *Sylphon aneroid barographs*, Fig. 15 (b), as developed by Julien P. Friez & Sons, Baltimore, have recently been placed in service in the bureau. Two parts of this instrument are essentially different from the Richard barograph, namely, the pressure element and the mechanism for adjusting the pen to the true pressure. The sylphon is an improvement over the aneroid shells heretofore used for barographs, on account of its freedom from elastic hysteresis. The sylphon is made in one piece like a bellows in the form of a corrugated tube of thin

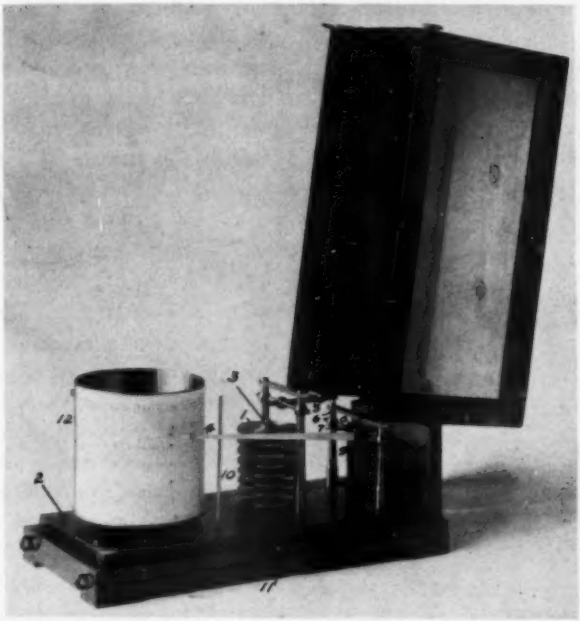


FIG. 15 (a) *Richard aneroid barograph.*

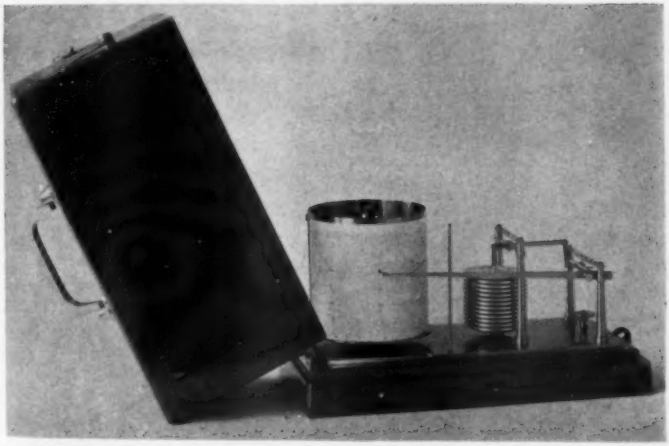


FIG. 15 (b) *Barograph with sylphon vacuum chamber.*

brass, one rather stiff spring within preventing collapse under atmospheric pressure when the element has been exhausted of air. The response to changes in atmospheric pressure is prompt, and there is but little error due to temperature change.

The turning of the milled-head thumb screw on the top of the base-plate near the right hand end gives the adjustment of the pen to current pressure to agree with readings of the mercurial barometer. The thumb screw operates to turn a pivoted lever arm, resulting in the slight raising or lowering of the entire sylphon.

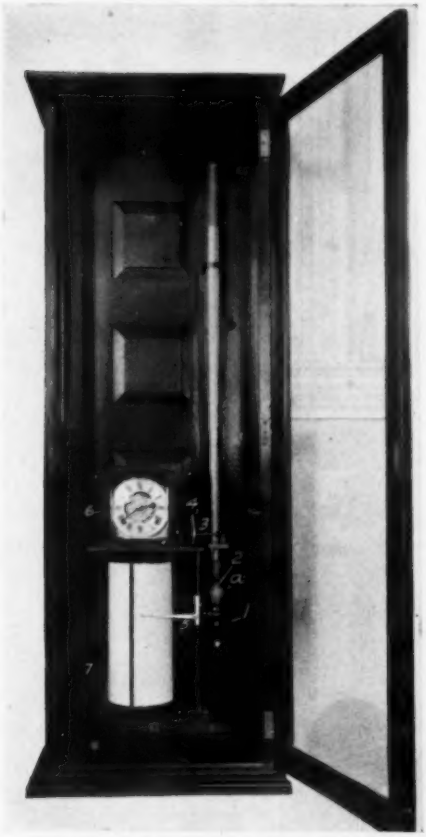


FIG. 16 *Marvin mercurial barograph.*

(c) *Marvin mercurial barograph*, Fig. 16, provides an open-scale record of atmospheric pressure. It was invented in 1904 by Prof. C. F. Marvin of the Weather Bureau.

Referring to the figure,—(1) is a special form of siphon barometer consisting of two straight tubes, (a) and (b), 1 1/4 inches inside diameter, having their lower ends carefully fitted into ground joints in the *U* bend of the siphon. A conical steel float, (2) rests lightly on the mercury in the open leg of the siphon, and attached to the float is a light metal hook to the upper end of which is fixed a narrow platinum ribbon which transmits the motion of the float to the small cylinder attached to axle (3). The axle, supported in ball bearings, carries the wheel (4) nearly 5 inches in diameter, and a fine copper wire running in a groove in the wheel supports the pen carrier, (5). The mechanism is so dimensioned as to produce a record

giving a five-fold magnification of the pressure changes. Clock (6) drives the record cylinder (7) and also operates an electromagnetic time-marking device so arranged as to lift the float slightly and then release it, thus causing the pen arm to oscillate up and down a few times, the pen writing a short vertical line across the pressure record. This action also serves to readjust the float and the linkage to a new position of equilibrium, and the return of the pen to its position before marking indicates a proper functioning of the instrument.

III. WIND-MEASURING INSTRUMENTS

At each of the first-class Weather Bureau stations continuous automatic records of the horizontal velocity and direction of the wind are secured by means of cup anemometers, and wind vanes respectively, both arranged for electrical registration. (See registers). Since the cup anemometer is essentially an integrating instrument, average velocities are obtained for greater or smaller time intervals, depending upon the requirement; e.g., for daily observations telegraphed for forecast purposes, the average velocity during a five-minute period is generally used, while for climatological purposes hourly averages and daily wind movements are mostly employed. The nearest approach to a momentary velocity is the so-called extreme velocity, determined from the least time required for the passage of a single mile of wind. At a few stations, however, the gustiness of the wind is registered by Dines pressure-tube anemometers, the records from which are usually in the form of a band resulting from the successive gusts and lulls, and a median line passed through such a record provides a way to determine average velocities in addition to the gustiness.

Besides the foregoing, indicating cup anemometers, anemoscopes or mechanically-recording wind vanes, and kite anemometers, both of the cup and fan types, are occasionally used.

1. ANEMOMETERS

(a) *Robinson cup anemometers, 4-cup type*, Fig. 17, have been employed in the bureau almost exclusively for wind-velocity measurements since 1871 with but little essential modification of the original construction. The first cup anemometer was introduced in 1846 by Robinson and afterwards developed and better adapted to meteorological work, especially in England, but always retaining its elementary form of four hemispherical cups mounted on horizontal transverse arms attached to a vertical spindle. This system is rotated by the wind and suitable

gearing provided for registering the wind movement on dials in miles and tenths of miles (or meters and tenths), assuming usually that the wind movement causing the rotation is three times the linear movement of the cup centers. This factor, three, was first supposed to be true for all sizes of cup anemometers. In fact it is not constant at all, but for a given cup wheel decreases as the velocity increases. The factors of cup wheels of differing cup dimensions and length of arm are also different at the same true wind velocity, and the factor is less variable

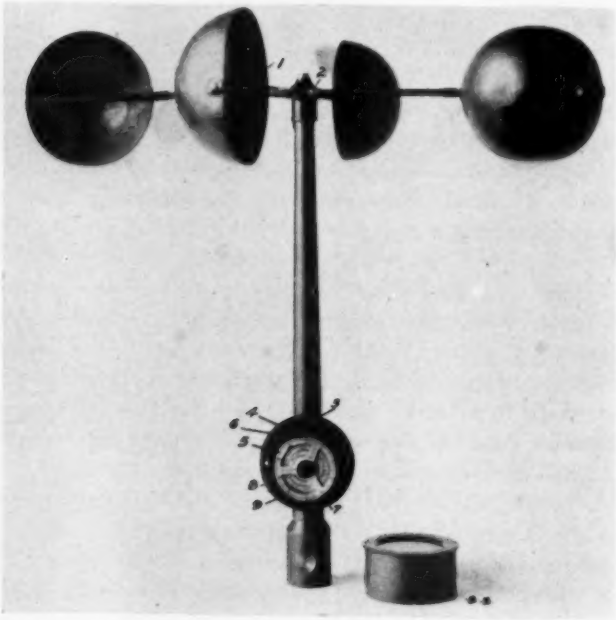


FIG. 17 *Robinson 4-cup anemometer; dial cover removed.*

for wheels having large cups on long arms and for those with cups set close to the vertical axis. A correction table is therefore required to give true velocities.

Recent tests of anemometers by the bureau have led to the development of the three-cup instrument described below, which has a more constant factor than the four-cup anemometer, and the indications of the instrument are very near the truth at moderate and low velocities, and at high velocities it is in error by only four or five per cent.

Referring to Fig. 17: The cup wheel (1) is made of four 4-inch hemispherical cups of thin aluminum or copper mounted on light weight square steel arms, with the cup centers 6.72 inches from the spindle. The wheel is attached by set screw (2) to a steel spindle within the casing having a plain bearing at the upper end and a step bearing at the bottom. A steel worm wheel on the spindle transmits motion to the wheel (3), on the axis of which is a second worm meshing with the pinion (4) which turns the two dial wheels, (5), the outer one of which has 100 teeth and the inner 99, so that for each revolution of the former, the inner wheel moves one graduation, equivalent to an indicated wind movement of 10 miles. The inner dial therefore gives the reading to tens of miles as referred to the zero of the outer dial and the latter gives the additional miles and tenths by reference to the index at (6). Electrical registration is secured by the closure of a battery circuit which includes a register magnet in the distant office. One side of the circuit is connected through the frame to post (8) to which spring (9) is also attached. The spring is pushed into contact with the insulated platinum point at (7) by means of the pins, ten in number, in the outer dial, which slide in turn over the lug (9) on the spring. Each mile of wind movement therefore produces a closure of the circuit through the register magnet which actuates the pen on the record sheet.

(b) *Robinson cup anemometer, three-cup type*, Fig. 18, (a) and (b), is similar in general construction to the 4-cup anemometer, and is just beginning to be placed in service instead of the latter. The desirable features of a cup-wheel with three cups were first demonstrated by J. A. Patterson of the Canadian Meteorological Service, and tests made by the Weather Bureau verified his findings, resulting in the design of a new 3-cup anemometer by S. P. Fergusson. The principal difference between the newer instrument and the 4-cup anemometer is in the cup-wheel itself, 5-inch cups being mounted on tubular arms, the cup centers being 6.29 inches from the axis of rotation. The use of a wheel with three cups instead of four, combined with the larger-sized cups, results in a more uniform rate, and the factor relating the linear movement of the cup centers to the wind movement which causes their rotation, is more nearly constant. To give nearly correct indicated readings at moderate velocities the gearing is based on a factor of 2.5, whereas a factor of 3 has been used for the 4-cup anemometer. Other changes involve improvements in constructional details.

(c) *Dine's pressure-tube anemometer*, Fig. 19, was designed by W. H. Dines, England, and introduced about 1891. Three of them are

FIG. 18 (a) *3-cup anemometer complete with wick oiler for upper bearing.*

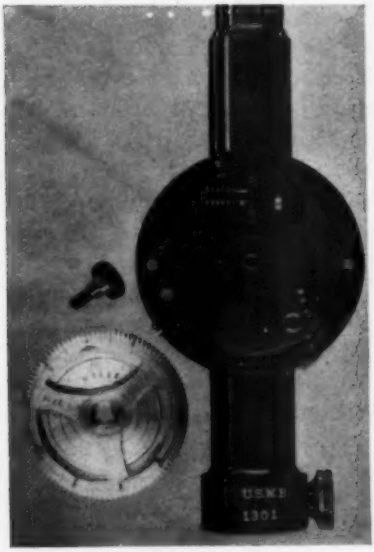


FIG. 18 (b) *3-cup anemometer, dials removed.*

in service in the bureau at present, the first of which was purchased in 1909.

There are two parts to the instrument, the head, Fig. 19 (a), which is exposed out of doors at a suitable place, and the recorder, Fig. 19 (b), located indoors and connected to the former by lead or iron pipes. The head, mounted on a rigid support, may be as much as 100 feet distant from the recorder. It is comprised of two portions, (1), the pressure

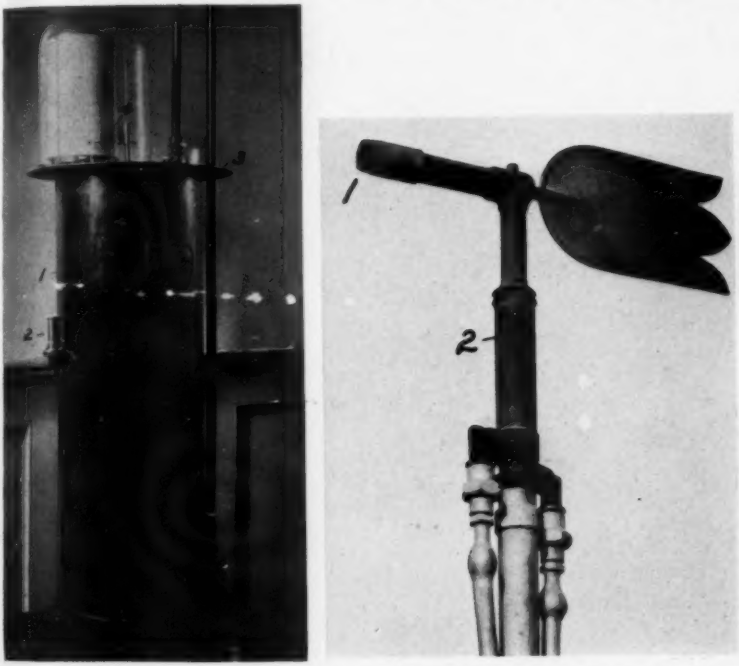


FIG. 19 *Dine's pressure-tube anemometer: (a) head; (b) recorder.*

tube and the attached vane to direct the tube into the wind, and, (2), the suction tube, with its wall drilled with a number of small holes through which the air has access to the annular space within. The constant of the instrument is determined largely by the number and size of these holes and the shape of the annular space. The connecting pipes transmit the suction and pressure to the outside and inside respectively of a copper float resting in pure water at a certain height within the cylindrical tank (1) of the recorder, as shown by the glass gage (2). Plate (3), forming an air-tight joint with the top of the float chamber,

carries the record cylinder, rotated once each 24 hours by the clock within. Variations in the wind velocity cause corresponding changes in the suction and pressure, which, combined, produce rises and falls of the float and the attached pen arm (4). Since the wind velocities are written directly on a scale of equal parts, while the pressure differences are proportional to the square of the velocities, the inside of the float has been so shaped as to be raised and lowered in proportion to the square-root of the velocity. The relation between the pressure difference, W, and the wind velocity, V, for the standard Dine's head is

$$W = .000731\ V^2$$

where W is measured in inches of water and V in miles per hour.

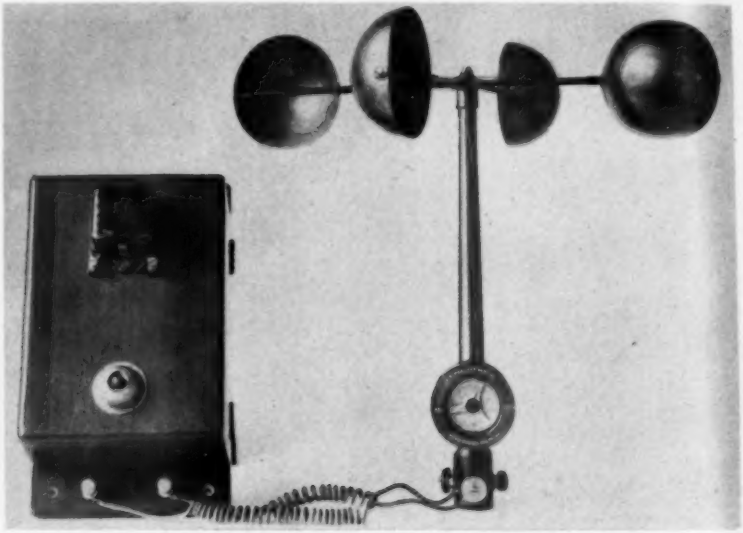


FIG. 20 *Indicating anemometer connected on short circuit with indicator.*

(d) *Wind-velocity indicator*, Fig. 20, (shown connected on a short circuit), is an adaptation of the cup anemometer introduced in 1916 by B. C. Kadel of the bureau under the name of 1/60 mile anemometer. It provides a simple means of determining the current wind velocity without a register. The electric contacts of the instrument are so made that the number of circuit closures per minute, as counted by an observer listening to a buzzer in the circuit, corresponds to the velocity in miles per hour. The anemometer, exposed where desired, is joined to the indicator by a two-wire circuit. Within the indicator is a 2-cell

dry battery, which is connected into the circuit when the button is pressed, and the observer with watch in hand counts the number of circuit closures per minute.

(e) *Kite anemometers* are illustrated and described under meteorographs.

2. WIND VANES

(a) *Four-foot wind vanes*, when used for recording direction, are given as free exposure as possible on a pipe support adapted for roof exposure, as shown in Fig. 100, or for mounting at the apex of a steel tower, Fig. 101. As simple non-recording vanes they also form a part of the regular equipment for storm-warning towers, being mounted at the top of the flagstaff. (See Fig. 102). The 4-foot vane was intro-

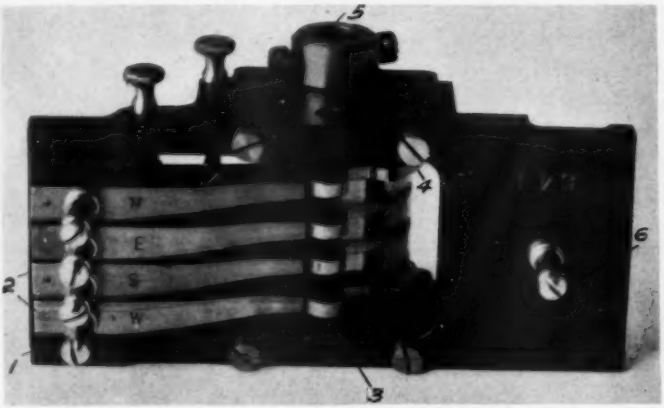


FIG. 21 *Wind-vane contacts.*

duced about 1900 for tower exposure and was first employed for recording purposes in 1907. It followed in general construction the vanes previously used in the service, which are named spread-tail arrow vanes, first employed in 1797 by Parrot in England.

Briefly stated, the 4-foot vane consists of two wings of thin wood united at the spindle and spread apart five inches at the leeward end, the windward portion being formed of an arrow-tipped iron rod carrying a counterweight to balance the vane about the spindle as a fulcrum.

For either recording or non-recording usage, the vane is securely fastened to a steel-rod spindle which usually turns in ball bearings. Wind vanes are made electrically recording by attaching to the spindle,

or to a pipe extension of the same, a contact-making device enclosed in a water-proof iron or aluminum box. In Fig. 98 (b), the wind vane (1) is carried on a thrust collar ball-bearing at (2). The spindle is coupled to 1/8-inch iron pipe extending from a point within the hand-hole (3) to the wind vane contacts placed in the box below. The bearing assembly (Fergusson model) is clamped to the support by the set screw at (4). Referring to Fig. 21, a larger view of the contacts separated from the box: The contact plate (1) carries four insulated springs, (2), and four rollers, (3), each mounted on a lever and held in position on the cams by a spring. Four exactly similar cams (4) are mounted on a common axis and turned by the wind vane and the iron pipe connection attached at (5) by set screws. Each cam, acting through three-eights of a circumference, overlaps the one below it by one-eight of a circumference. The turning of the cam axis by the vane operates to close an electric circuit, when one or two of the levers carrying the rollers is forced into contact with the springs (2). The overlapping of the cams furnishes a record of the wind directions intermediate between the cardinal points, that is, to eight points in all. One side of a battery is connected to post (6) and the closure of the circuit through the contact springs operates one or two electro-magnets and their attached printing points on the distant register at intervals of a minute. (See quadruple registers).

(b) *Six-foot wind vanes*, Fig. 22, are constructed in a similar manner to the 4-foot, but are employed for recording purposes only. They were introduced in 1892, replacing a 3-foot vane. A special roller bearing is used instead of a ball-thrust bearing.

(c) *4-foot aluminum wind vane*, Fig. 23, is an all-metal vane designed by S. P. Fergusson in 1923. It is of the same type as those previously described, but the height of the tail of the vane has been increased considerably as compared with the 4-foot vane with wooden tail. The height at the spindle is 8 inches increasing to 11 inches at the leeward end; the spread is 6½ inches. This increase in the height of the tail, while maintaining light weight by the use of sheet aluminum, increases the sensitiveness of the vane. The durability should also be considerably greater than that of a wooden vane.

3. ANEMOSCOPES

Anemoscopes, Fig. 24, of the Draper pattern, (invented about 1875) and as redesigned for portable use by S. P. Fergusson, have been employed in Weather Bureau field work to a slight extent since 1917 to

secure records of wind direction without the use of electrical devices. They are also convenient because of their portability.

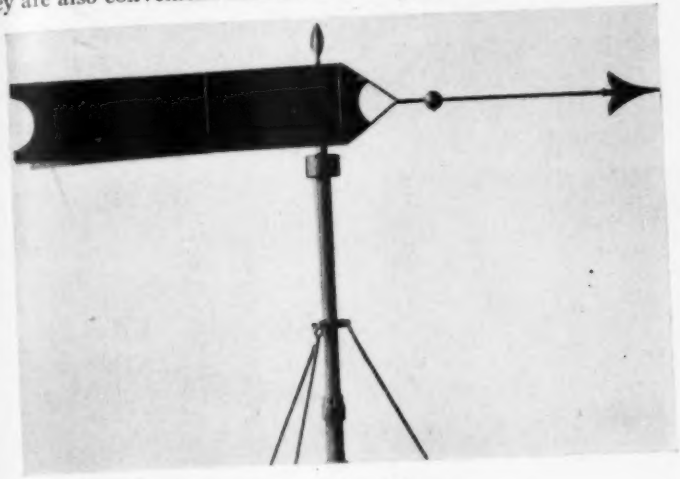
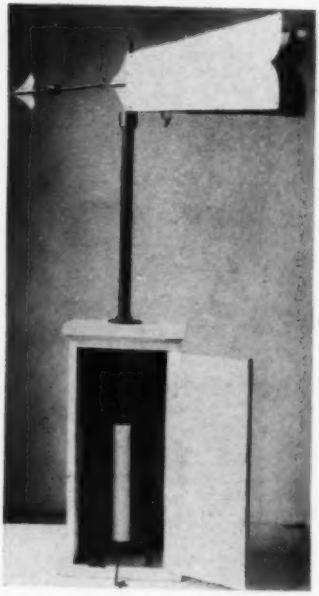


FIG. 22 *6-foot wind vane.*

FIG. 23 *4-foot aluminum wind vane.*

Referring to the figure:—The wind vane (1) is of the same all-metal type shown in Fig. 23. Its motion is communicated to the record

cylinder (2) by means of the spindle (3) which rotates in a bearing within (4). The spindle is carried on a step-bearing at (5). The pen carriage (6), supported by means of a chain from an arbor on the clock (7), moves the length of the record sheet from top to bottom during a period of 24 hours. The record sheet is graduated to give directions to eight points and time in 1/4 hours. Intermediate values may be readily interpolated.



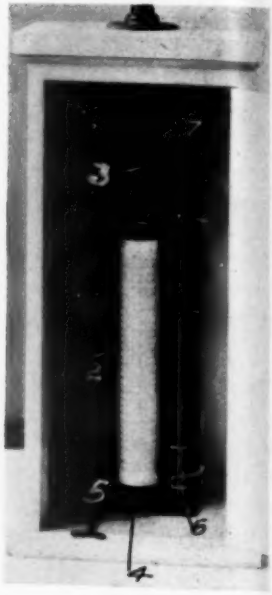


FIG. 24 *Anemoscope, Fergusson pattern.* *Details of recorder.*

IV. PRECIPITATION GAGES; OMBROSCOPES

Several forms of gages are maintained throughout the service for the measurement of the vertical depth of fall of rain, snow, or hail, the unit of measurement being the inch. Rainfall and the water equivalent of snow or hail are recorded in inches and hundredths. The precipitation measured in the gage is assumed to be the total depth that has fallen uniformly on a horizontal surface of small area during a given time period without loss by drainage, seepage, or evaporation. For official observations the collectors of the gages employed are circular in form and usually eight or twelve inches in diameter, and to measure accurately rainfall in hundredths of an inch, the actual depths are

multiplied by ten by using a measuring tube which has an area of cross-section one tenth that of the collector.

The depth of rain collected in a gage can be measured with but little error; the difficulty lies in catching the rain, or in other words accurate rainfall measurements are principally connected with securing a proper exposure of the gage to avoid or lessen wind effects which prevent a true catch. Wind shields, as used in certain of the gages described, also increase the accuracy of the catch by deflecting the wind downward, thus preventing its sweeping over the gage and forming eddies which interfere with the fall of rain or more especially snow into the collector. The standard exposure of the eight-inch gage places the mouth of the collector nearly 37 inches above ground, or above a roof when the preferable ground exposure is not practicable. The mouth of the collector of the tipping-bucket gage is about 36 inches above the surface on which it stands. The mouth of the collector of any gage must be level.

Still greater difficulty is found in catching snow in a gage because of the wind. Reliance is therefore placed principally in direct measurements of the depth and density of snow which falls on a level surface as little disturbed by the wind as practicable. Special appliances for snowfall measurements are described in Section XIII.

The precipitation gages at a first-class station include one 8-inch gage and one 12-inch tipping-bucket gage for rainfall, and an 8-inch gage overflow can for occasional snowfall measurements when there is little or no wind. Eight-inch gages are also used at cooperative stations. The balance of the equipment finds limited and special usage as given in detail below.

1. EIGHT-INCH RAIN AND SNOW GAGES

Historically rain gages were found to have been used in Korea as early as 1422. Gages with funnel collectors appeared in 1677, the weighing method of measurement being used. In 1722 a gage was introduced by Horsley of Northumberland, embodying the modern principle of using a measuring tube of relatively small area of cross-section as compared with the collector in order to magnify the depth for measurement. A collector with a deep rim was first employed in the Snowdon gage in England in 1854.

So far as the Weather Bureau is concerned the standard 8-inch gage in its present form dates from 1890, being preceded by an 8-inch collector combined with a 6-inch overflow, introduced when the service

was organized. Measuring tubes magnifying the depth by 10 were used in both forms.

Fig. 25 (a) and (b) illustrate the assembled gage mounted in two forms of support; (a), an iron-tripod used at first class stations, and, (b), a less expensive box support. The parts of the gage are shown in Fig. 26. The collector (1) is made of brass tubing with the outside bevelled to a sharp edge at the top so as to properly define the area of collection, which is a circle 8 inches in diameter, or the inside diameter of the tub-

FIG. 25 (a) *8-inch rain and snow gage with iron-tripod support.*

FIG. 25 (b) *8-inch rain and snow gage with box support.*

ing. The collector is soldered to a galvanized-iron funnel having an opening at the small end of 5/8 inch, just large enough to permit of the insertion of the measuring stick. The collector is also so formed as to fit over the upper ends of the 8-inch overflow can, (2), (See Fig. 26), and the brass measuring tube (3), which stands centrally within the overflow. The measuring stick (4) is made of cedar 24 inches long and graduated into inches and tenths, and, since the area of cross section

of the measuring tube is one-tenth that of the 8-inch collector, the depth of water finding its way into the tube is ten times that which has fallen. Ten inches on the measuring stick therefore correspond to one inch of rainfall and the nearest hundredth of an inch of rainfall is easily read. When the rainfall exceeds two inches, the capacity of the measuring tube, additional water passes into the overflow can from which it is poured into the tube for separate measurement and its depth added to the two inches already measured.

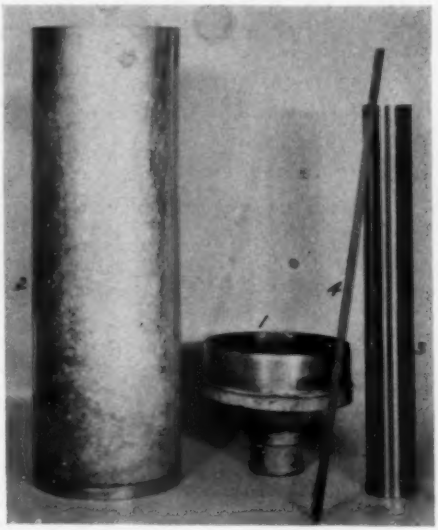


FIG. 26 *Details of 8-inch rain and snow gage.*

2. TIPPING-BUCKET RAIN GAGES

(a) *12-inch tipping-bucket gages (for electrical registration)*, Fig. 27, are used for securing automatic records of rainfall in connection with a suitable register. (See registers, page 376) At the first-class stations of the bureau these gages are the standard, excepting during freezing weather, when their use is impossible.

There is record of a tipping-bucket gage devised in England by Sir Christopher Wren in 1662. Other gages appeared from time to time, most of them arranged to indicate the total rainfall on a dial. One by Negretti and Zambra, London, provides a record by mechanical methods. The Weather Bureau gage was designed by Prof. C. F. Mar-

FIG. 27 (a) *Tipping-bucket rain gage.*

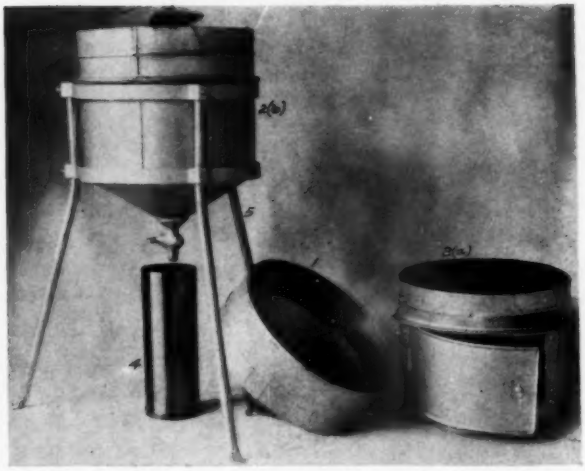


FIG. 27 (b) *Tipping-bucket rain gage parts.*

vin and introduced in 1894 and has been used with little modification since.

Referring to Fig. 27, the collector, (1), is made of brass tubing 12 inches inside diameter, bevelled to a sharp edge, its lower end soldered to a galvanized-iron cylinder and funnel so shaped as to fit over the tank portion of the gage, (2). The latter contains the tipping bucket and frame, (3), mounted on insulated brackets. The bucket and frame are also shown separately in Fig. 28. The door and removable collector provide easy access to the bucket mechanism. Rain falling into the collector is directed into one of the two compartments of the bucket, which are so proportioned by weight and form as to hold very nearly one-hundredth of an inch depth of rainfall, which for rainfalls of average intensity is sufficient to over-balance or tip the bucket, (1), (See Fig. 28),

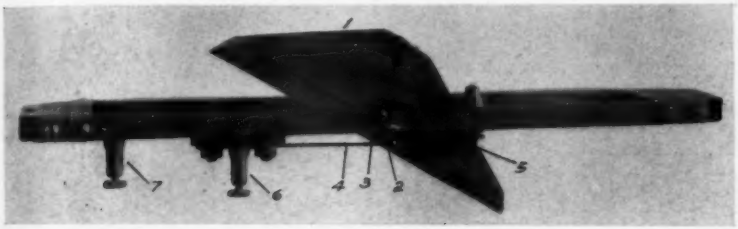


FIG. 28 *Tipping-bucket and frame.*

causing it to rotate to a stop about the axis at (2), thus bringing the other compartment of the bucket under the funnel of the collector to repeat the operation. The water passing through the bucket falls into the bottom of the tank from whence it is drawn at observation time into the measuring tube, (4), Fig. 27, and measured with the same cedar scale used with the 8-inch gage. The manner of mounting the gage in the iron-tripod support, (5) is evident from Fig. 27.

Records are produced by the closure of an electric circuit with each tip of the bucket. Lug (3) attached to the bucket, (Fig. 28) pushes the insulated spring (4) downward until the contact is closed at (5), which permits current to flow from the insulated post (6) through the spring to post (7) grounded on the frame. The circuit includes a suitable battery either primary or storage and an electromagnetic registering device. (See registers, page 376).

The degree of accuracy of the records obtained with a tipping-bucket gage varies principally with the rate of rainfall. The buckets are

adjusted to register correctly for rainfalls of moderate intensity so that the record of a rainfall of greater than this intensity is deficient in amount as compared with a stick measurement of the rainfall passed through the gage, and such a record is corrected by interpolation. Conversely the record of a slow rainfall would show a slight excess. The presence of dirt in the bucket, corrosion of bucket or contacts, failure to level the gage, etc. are also factors affecting the accuracy.

(b) *The kiosk tipping-bucket gage (for mechanical registration) Fig. 29*, was designed by Prof. C. F. Marvin and introduced in 1905. The instrument is built into the kiosk (See also Fig 85, page 401), the collector (1), 15 inches square being placed within the top. Rain falling therein is conducted through the lead pipe (2) to a point central over

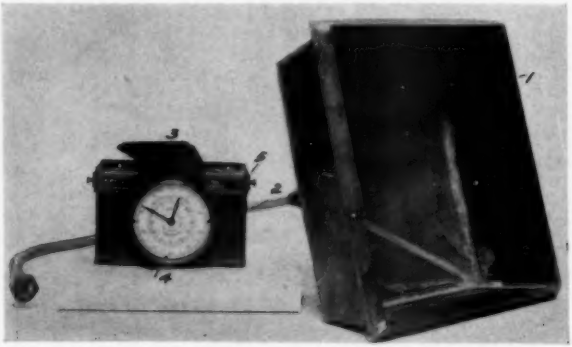


FIG. 29 *Kiosk tipping-bucket rain gage.*

the pivots of the bucket (3). A ratchet and ratchet wheel with gearing are actuated by each tip of the bucket and the two hands are made to move over the dial (4), the short hand indicating the inches and the long one the hundredths of an inch. The counters (5) are not a part of the gage, but are displayed in the kiosk and set daily for the benefit of the public to show the accumulated rainfall from Jan. 1st to date each year and for comparison with the normal rainfall for the same period.

3. SHIELDED RAIN AND SNOW GAGES

This gage is provided with a modified Nipher wind shield made of sheet iron, and, with the exception of the Marvin float gage, is the only one of the bureau's gages including such a shield. The gage was designed by Prof. C. F. Marvin in 1910 mainly for the measurement of

snow in windy locations in the western mountain regions, where a number of them are now in use.

FIG. 30 *Shielded rain and snow gage: (a) exposed for mountain-snowfall measurements.*

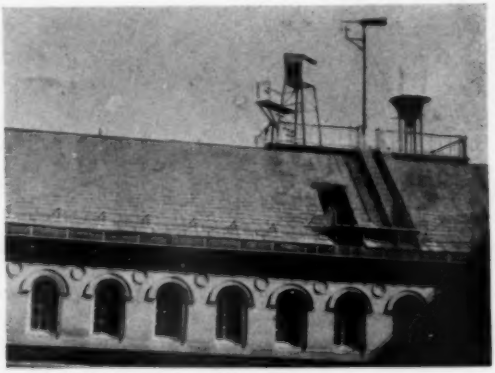


FIG. 30 (*b*) *Exposure on roof of Weather Bureau building, Denver, Colo.*

Referring to Fig. 30 (a). The collector (1) is a galvanized iron can 10.85 inches inside diameter and 34 inches deep inside, carried on an

adjustable support (2) formed of two iron pipes, the inside and lower one embedded in the concrete plinth underneath the snow in the figure, the upper one surmounted by a pipe rail base attached to a block of wood (3) which fits into the recessed bottom of the collector in place, so that its mouth is correctly positioned with reference to the shield (4). The square frame of the gage is built of angle irons and securely braced with rods; the corner posts and plates being secured by bolts embedded in concrete. Four guy-rope anchors (5) are also attached when the erection of the gage is complete. One of the upper girts (6) is extra long and has a chain and hook at its outer end to carry a special spring balance.

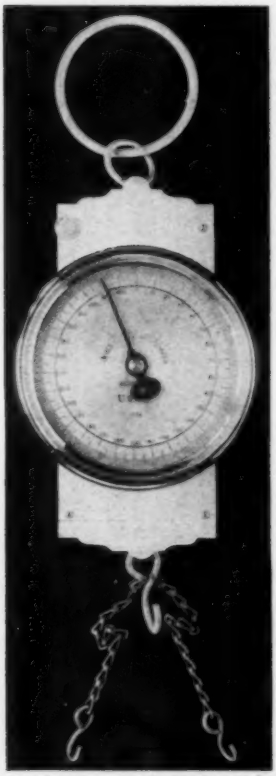


FIG. 31 *Balance for shielded rain and snow gages.*

To measure the precipitation, latch (7) is pulled out, the collector dropped, removed from the support and can and contents weighed on a special balance hung from the hook. This balance, shown separately in Fig. 31, has a capacity of 30 lbs. in three revolutions, and, since 3 inches of rain or melted snow in a collector 10.85 inch in diameter weigh 10 lbs., the dial is so graduated that the precipitation may be read directly in inches and hundredths. The weight of the collector itself is just sufficient when placed on the balance to bring the pointer to zero; any dial reading greater than zero represents the rainfall or the snow equivalent.

4. FERGUSSON WEIGHING RAIN AND SNOW GAGE

This portable gage, Fig. 32, records the amount of precipitation in any form, also the time of its occurrence, at the place of exposure of the gage. It was designed by S. P. Fergusson and was introduced into the Weather Bureau in 1922, the construction being similar to an earlier pattern first made by him and used at Blue Hill Observatory in 1888.

Referring to Figs. 32 and 33, the latter illustrating the dissembled gage: The 8-inch collector (1), contains a removable funnel (2) (not

seen in illustrations) which prevents evaporation of rainfall, but is omitted when snow is expected. The collector assembly fits over the case (3) as seen in Fig. 32, the latter being attached to the cast-iron base (4) on which the recording mechanism is mounted. Precipitation falling into the collector flows thence into the receiver (5), a cylindrical copper can resting on the platform (6) of the balance. The weight of the precipitation and receiver is balanced by the coiled steel spring (7) which is adjustably attached to the bracket (8) supported by the column

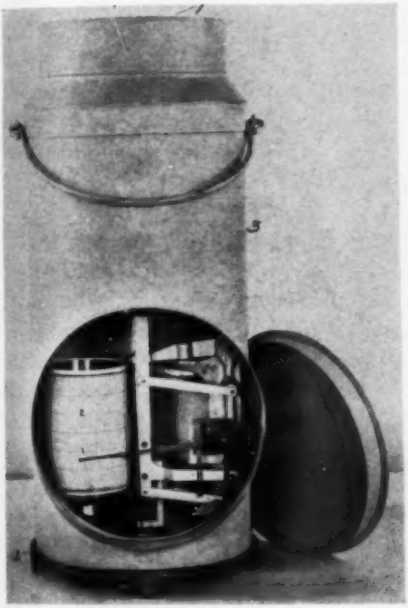


FIG. 32 *Fergusson weighing rain and snow gage.*

FIG. 33 *Details of Fergusson gage.*

(9) rigidly screwed to the base. The motion of the platform is transmitted to the pen mechanism through the yoke (10) rigidly attached to the platform, both yoke and platform being constrained to move over a nearly vertical path by the rocker arms (11). Adjustment of the pen on the record sheet is made by the screw, (12). To minimize the effects of wind pressure in causing vibrations of the balance, a dash pot containing glycerin is employed to damp the motion of the moving parts.

The gage has a capacity of 9 inches of rainfall which is recorded in three traverses of the record sheet by means of a four-bar linkage at (13). The clock-driven record cylinder (14) makes one revolution in 24 hours.

5. FLOAT RAIN GAGES

(a) *Marvin float rain gage.* The first rain gage making use of a float to indicate the depth of rainfall appeared in 1787, and is ascribed to Kite and used at Gravesend, England. There have been numerous others since, and about 1888 a few of the 8-inch gages of the bureau were modified by using a float in the 2.53-inch brass measuring tube, the rise of the float actuating a device to close an electric circuit for each small increment of rainfall, and thereby produce a record on a distant register.

Gages of this type are used to some extent in obtaining rainfall records when it is not convenient or desirable to employ an electrically-recording gage. Those in service have been valuable in connection with rainfall studies for engineering purposes.

The gage, Fig. 34 (a) and (b), was designed in 1913 by Prof. C. F. Marvin. It consists of three parts: first, the 8-inch collector (1) built into the rectangular sheet metal case or cover (2), which carries the wind shield (3); second, the recording mechanism mounted on the cast-iron top plate (4); and third, the receiver, (5), carried on the casting, (6), which together with the legs and top plate form the support, slightly more than 2 feet high.

The assembled gage is shown in Fig. 34 (a); in Fig. 34 (b) the collector-cover has been removed to give a view of the details of the recording mechanism.

Rain falling into the collector passes through a brass tubing into the small funnel (7) which surmounts a pipe reaching nearly to the bottom of the receiver. Within the receiver is a copper float suspended by a flexible brass chain (8) passing over the pulley (9) to the small drum (10) where it is attached. The float is balanced by means of a counterweight suspended from the drum (10) within the pipe (11). When the gage is started in operation enough water is poured into the receiver to free the float and permit the adjustment of its level and consequently that of the pen on the record sheet by means of the spigot (12) through which water may be withdrawn as desired. A thin layer of kerosene on top of the water prevents evaporation.

As the water and the float rise in the receiver, their motion is transmitted through the chain and pulley to the drum (10), causing the

FIG. 34 *Marvi nfloat rain gage: (a) complete gage assembled for use.*

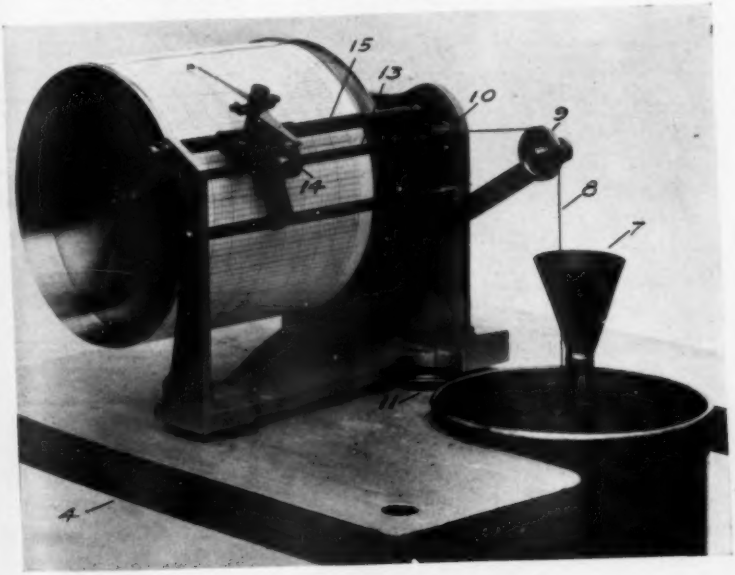


FIG. 34 (*b*) *Near view of recording mechanism.*

latter, together with the axis (13) to which it is attached, to rotate. A cylindrical cam, (14), also attached to the axis produces a back and forth motion of one-half inch of the pen across the record sheet, each swing corresponding to a rainfall of 0.25 of an inch. A week's record is secured, the pen mechanism (14) being moved by means of the screw (15) turned by the clock within the end of the record cylinder through suitable gearing. The cylinder revolves once each day so that the record appears in the form of a spiral beginning at one end of cylinder and ending at the other.

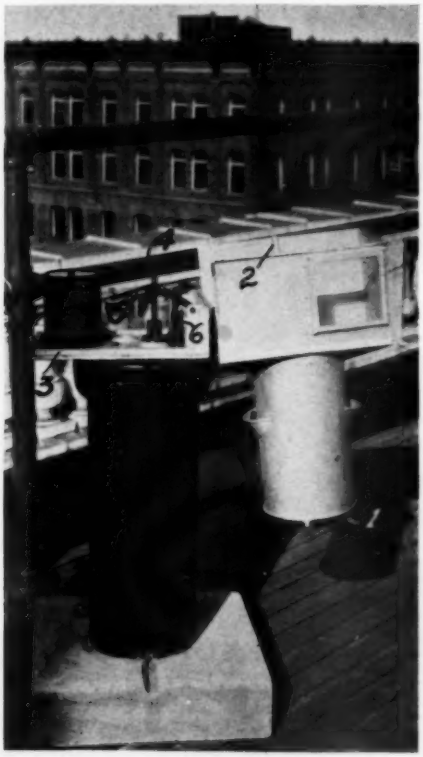


FIG. 35 *Hyetograph.*

(b) *Hyetograph,*—This is another form of portable rain gage by which a record is secured by mechanical means including a float. It was designed by F. L. Halliwell, England, in 1907, and two of the instruments were secured for Weather Bureau work in 1922.

Referring to Fig. 35, the 6-inch collector, (1), is of the usual construction, excepting for having a considerably deeper rim than is customary for American gages. Rain falling therein passes through the funnel and a central tube (2) into a receiver below the baseplate (3). The water rising in the receiver lifts a float and an attached vertical rod (4) having projecting pins set into it at intervals corresponding to increments of one-half inch of rainfall. Beginning at the top-most pin, the pen arm (5) is raised until the half-inch of rain is recorded and then drops to the next pin, the pen returning to the zero at the bottom of the record sheet. The capacity of the gage is 4½ inches. A dash pot (6) damps the fall of the pen arm when it is released. An ingenious feature is the manner in which water is removed from the receiver. When more than one inch of rainfall has been collected, the pen arm is swung free from the rod (4) which is raised about 2 inches and then depressed, causing the water to flow over the head of a siphon. The siphon continues in operation until the receiver is drained.

6. OMBROSCOPES

This instrument is used at a few stations to obtain automatic records of the beginning and ending of rainfall. It is particularly useful for night records, but in the day time it will show the time of occurrence of light sprinkles that might otherwise pass unnoticed.

A similar device first appeared about 1860, constructed by M. Hervé Mangon, Paris, France. In 1895, Dr. O. L. Fassig of the Weather Bureau devised and used an ombroscope which was also utilized in a modified form at Blue Hill Observatory after the design of S. P. Fergusson. In 1920 Mr. Fergusson rebuilt the instrument to the form shown.

Referring to Fig. 36:—The sheet iron cover (1) is semi-cylindrical in shape and in the center of its top is a small rectangular hole, (2). Drops of rain fall through the hole on to a cylinder (3) rotated once each six hours by a clock within. The record sheet on the cylinder is cross-hatched with close-spaced diagonal lines in addition to the time lines, all being printed with copying ink. Any small drop of water causes the ink to run and produce a spot, and the duration of the rainfall can thus be quite accurately timed.

The instrument is provided with a substantial cast-iron base (4) to which the cover is secured, and on which the supports (5) for the clock axis are mounted. The cylinder containing a clock is built of aluminum and is 7½ inches in diameter, a steep screw (6) on the axis giving a

lengthwise motion of the cylinder of one inch for each 6-hour rotation, so that the record is in the form of a spiral around the drum, the center of the one-inch space being at all times beneath the hole in the cover.

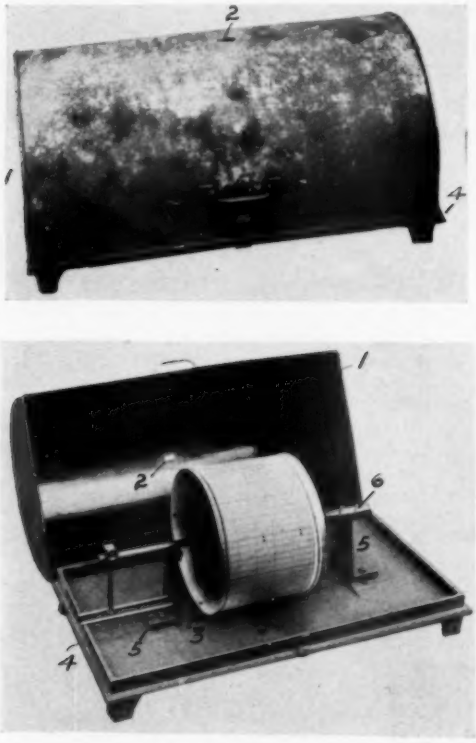


FIG. 36 *Ombroscope.*

V. NEPHOSCOPES FOR MEASURING THE APPARENT VELOCITY, AND THE DIRECTION OF MOVEMENT OF CLOUDS; SUNSHINE RECORDER GIVING ITS DURATION; AND POLE-STAR RECORDERS

1. NEPHOSCOPES

The use of the mirror nephoscope dates back to the year 1845 when the first one was designed by Aimé of France according to the principles of the method invented by Wartmann and Bravais in 1842. The first Weather Bureau nephoscope was designed by Prof. C. F. Marvin in

1896, its use continuing to a limited extent until 1919 when the form illustrated was introduced.

Observations of the kind, amount (i.e., the percentage of sky covered), and direction of movement of clouds, form a valuable part of the current observational work both for forecast and climatological purposes, largely as an index to movements of the upper air. Eye observations are principally employed, and are the only means for determining the kind and amount of clouds, but the nephoscope, with which about half of the first-class stations are equipped, provides a means for accurately finding the direction of movement and if desired the apparent velocity, from which the true velocity can be computed when the elevation of the clouds is also known.

Referring to Fig. 37, in (a) the complete nephoscope is shown. The copper cover which sets over the top plate will be observed to one side; (b) is a near view of the instrument proper; (c) accessories employed in setting up and operating.

Referring to Fig. 37 (a); the support for the nephoscope (1) is made of 3-inch pipe, (2), screwed to the heavy cast-iron base plate (3), bolted in turn to the concrete slab (4) which latter is provided with large leveling screws (5). The pipe is also screwed to plate (6) bolted to the flange (7) the upper surface of which is turned true and adjusted level so that the mirror of the nephoscope placed thereon is also level. The balance of the equipment includes the movable eyepiece stand (8), a heavy iron casting carrying the sighting eyepiece (9), and the copper cover (10) which protects the nephoscope against the weather when it is not in use.

The nephoscope, shown more clearly in Fig. 37 (b), consists of a black mirror nearly 9 inches in diameter mounted in a circular brass frame graduated in degrees. Three posts screwed into the nephoscope frame carry the mirror on the top flange of the support. The clock, scale, and triangular marker pictured in Fig. 37 (c) are used for observations.

Briefly stated, the nephoscope mirror is used to follow the movement of a cloud by observing its reflection. The eyepiece stand is moved about the mirror and the horizontal arm carrying the eye-piece adjusted until the observer sighting through the eye-piece sees the cloud image at the center of the mirror. He then follows its movement toward the periphery and notes the graduation in degrees of azimuth where the image would leave the mirror, and if desired, converts the readings in degrees into an eight or sixteen-point system of directions. Because a cloud image is being observed, the zero of the scale is set toward true

FIG. 37 (a) *Nephoscope complete with support.*

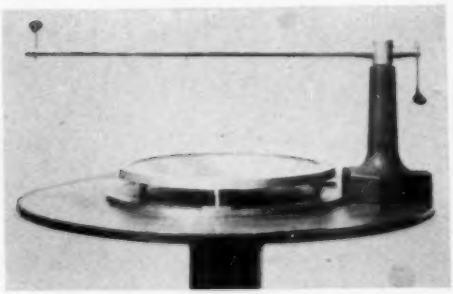


FIG. 37 (b) *Near view of nephoscope with eye piece and stand*

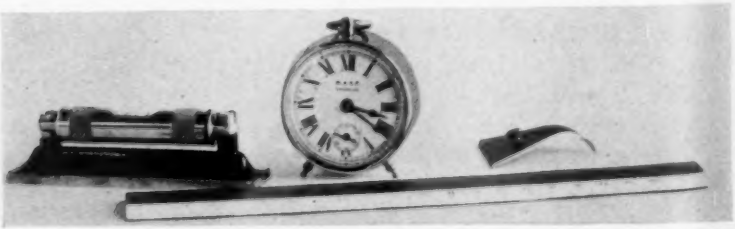


FIG. 37 (c) *Accessories for nephoscope.*

north, 90° is toward east, etc. Direct readings, therefore, give degrees of azimuth. The scale reading where the cloud image crosses the periphery is the direction or azimuth from which the clouds come. Cloud directions, like wind, are generally recorded to the nearest point of the compass from which they come.

To obtain the apparent or nephoscopic velocity of the cloud, the time in seconds the cloud takes to traverse a measured number of millimeters across the mirror is found. If the height of the cloud and the height of the sighting hole in the eye-piece above the mirror are known, the true velocity of the cloud is found by the following formula:

$$V = \frac{d \times H}{t \times h}, \text{ where}$$

V = velocity in meters per sec.
d = length in millimeters of path of cloud image
H = height of cloud
t = time in seconds for cloud image to pass over path, d
h = height of eye piece hole above mirror.

When h is made 166 2/3 mm and H is assumed to be 1000 meters, the number of centimeters crossed by the image in one minute equals the velocity of the cloud in meters per second.

2. SUNSHINE RECORDERS

The first instrument for obtaining a continuous record of sunshine dates from 1853, when a device was produced by John Campbell, of Islay, Scotland, employing a burning lens made by filling a hollow glass sphere with acidulated water. Later solid, spherical glass lenses were used, and the present British standard sunshine recorder is of this type. The lens is carefully focused on a card and the charring of the card gives a record of the duration of the sunshine, and, roughly, its comparative intensity.

Photographic sunshine recorders of the Jordan pattern produce similar results, and in 1891 the Weather Bureau began the use of an instrument of this kind designed by Prof. C. F. Marvin. In 1893 the mercurial recorder illustrated in Fig. 38 was introduced, developed also by Prof. Marvin. This instrument, however, is intended to furnish a record merely of duration when electrically connected with a register; intensity records are now obtained only with pyrheliometers. (See page 359). The use of the photographic recorder was discontinued in 1905.

The mercurial sunshine recorder illustrated is an adaptation of a Leslie differential air thermometer, an invention of more than a hundred years standing. In Fig. 38, the adjustable brass support, (1), carries a glass tube (2) about 7/8 inches in diameter and 11 inches long. Within this tube is a second glass tube, (3), joined to bulbs (4) at each end, and extending nearly to the bottom of the lower one coated with lamp black. The space between the two tubes is exhausted of air, so that the inner tube is not sensitive to ordinary changes of temperature of the air surrounding the instrument. A proper amount of pure mercury is introduced into the inner tube and bulbs, and also a small

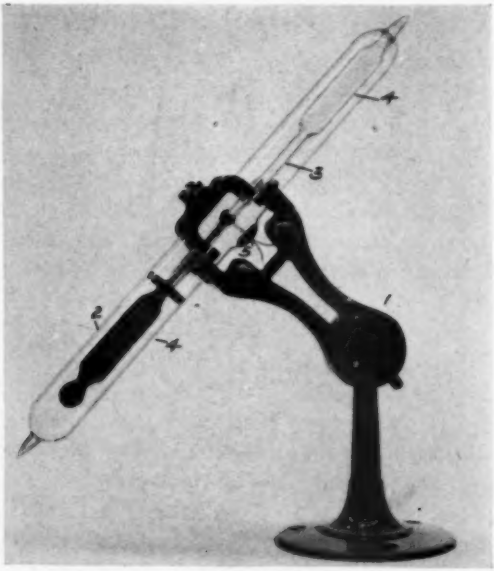


FIG. 38 *Mercurial sunshine recorder.*

quantity of pure alcohol. The axis of the tube is placed in the plane of the meridian, and inclined at an angle of about 45 degrees to the horizontal. When the sunshine falls on the blackened bulb, the air within becomes warmer than that in the upper clear bulb, and expands, thus forcing the mercury up the narrow tube until it closes an electrical circuit formed by two platinum wires fused into opposite sides of the tube at (5). The inclination of the recorder and the height of the mercury are so adjusted that when the sun's disc is faintly observed through

thin clouds, the mercury will just close the circuit, but because of the greater thermal effect when the sun is near the meridian such critical adjustment is best made to the average condition given by the mid-afternoon or forenoon sun. When the electrical circuit is completed at the recorder, a clock contact at the register closes the circuit each minute, thereby energizing a connected electromagnet which in turn actuates a pen on the register. (See quadruple registers, page 376). The alcohol previously mentioned serves as a lubricant and to prevent excessive sparking across the wire terminals. The tube is exhausted of air through its lower end and then sealed; the mercury and alcohol are introduced through the upper end which is also sealed.

3. POLE-STAR RECORDERS

There are very few of these instruments in existence. The Weather Bureau has one in service at Chicago; there are others at Blue Hill and Greenwich Observatories, and possibly another in use in Germany.

The pole-star recorder was invented by Prof. E. C. Pickering of Harvard College Observatory in 1885, and a modification first used at Blue Hill for meteorological work in 1885. A recorder of the same character embodying improvements by S. P. Fergusson was placed in service at Blue Hill in 1904. One of these recorders was secured by the bureau, and efforts to improve the device resulted in the instrument illustrated, which was installed at the University of Chicago station in 1917.

Referring to the illustration, Fig. 39:

Brass tube, (1), 4 inches in diameter and 87½ inches long, has a lens of nearly 75-inch focus mounted at its outer end; the aperture is 3 7/16 inch. The lens is mounted in a suitable holder which screws into a fitting fastened to the tube, and a shutter holder fits over the lens holder. The tube is pointed towards true north and a photograph of the trail of the north star secured as an arc of nearly $1\frac{9}{16}''$ radius on a $4\times5''$ film exposed in a holder (2) attached to the lower end of the tube. When clouds obscure the star, the continuity of the trail is interrupted, so that a good record of the duration of cloudiness at night is obtainable, and some indication also of the variation in cloud density. Clock (3) mounted on the upper side of the tube near the lower end controls the time of opening and closing of the shutter, a manual adjustment being provided for changing these times from day to day. An ingenious device is used to photographically mark a time scale and other information on the film before its night-time exposure. A dial of thin

metal is perforated with a circular scale of graduations showing hours and sixths for the 24 hours of the day. By means of a worm and a 365-toothed wheel to which the dial is secured this dial is rotated about the axis of the camera tube to a position which agrees with the changing angular position of the pole star from day to day, one turn of the worm sufficing to move the dial 1-365th of a revolution, thus keeping the time scale in right relation to the star trail after the initial setting of the dial.

FIG. 39 *Pole-star recorder.*

The time-scale device is inserted between the film and the lens and when the shutter is opened for a moment allowing daylight to reach the film through the graduations, the resulting record after the night-time exposure following appears as shown in Fig. 40. The record is then read directly in the mean solar time of the standard meridian of the station.

VI. HUMIDITY-MEASURING INSTRUMENTS

For accurate hygrometric work the Weather Bureau employs as a a primary instrument for precision measurements the whirled or ven-

tilated wet and dry-bulb psychrometer. All first-class stations are equipped with these psychrometers and three observations are customarily made daily. About 70 stations also have hair hygrographs by means of which a record of the relative humidity is obtained. These records, however, must be and are carefully checked against the relative humidities computed from observations with the psychrometer. Hair hygrometers are used only for display in the kiosks or street instrument shelters to furnish an easily-read indication of the relative humidity for the benefit or interest of the public.

FIG. 40 *Record from pole-star recorder.*

1. WET AND DRY-BULB PSYCHROMETERS

According to Abbe the first use of a wet and dry-bulb psychrometer is ascribed to Paume, who introduced one in 1767. The readings, however, only served as an indication of the moisture present in the atmosphere until tables were computed by E. F. August in 1825, showing roughly the relation of the dew-point temperature to the difference between the readings of the wet and dry-bulb thermometers. Others connected with the development of the instrument are Cullen (1777), Saussure (1786), Hutton (1792), Leslie (1799), Boechmann (1802), Gordon (1817), and Mason 1836).

The need for artificially ventilating the psychrometer was appreciated, by Saussure, who whirled the wet bulb, and a sling psychrometer was suggested by Arago in 1830. Belli (1831) effected the same results by,

placing the psychrometer in a controlled current of air, and a sling psychrometer was devised by Bravais in 1836 and later adopted by the French meteorologists. More recent advances in psychrometry were mostly concerned with accurate dew-point and vapor pressure measurements coupled with simultaneous readings of the psychrometer, by means of which reliable tables could be constructed through the medium of a psychrometric formula giving the pressure of aqueous vapor corresponding to the depression of the wet-bulb thermometer.

The Weather Bureau psychrometric tables at present used were developed by Prof. C. F. Marvin and published in 1900. They are based on Ferrel's psychrometric formula, and are applicable only to a wet bulb whirled with a linear speed of about 15 feet per second, or subjected to an air current of the same speed.

In the Weather Bureau service stationary wet and dry bulb hygrometers were used until 1886, when the whirled or sling psychrometer was introduced.

(a) *Psychrometer for machine whirling*,—The so-called whirling apparatus used at first-class stations is illustrated in Fig. 41. Two accurate stem-graduated mercurial thermometers (1) and (2) of the kind described under thermometers, page 302, are mounted on supports attached to the counterbalanced iron arms (3) and (4), the hubs of which are pinned to a spindle carrying a cast-iron pinion (5). As readily seen, the whirling of the thermometers is accomplished by turning the bevel gear (6) and attached crank shaft (7). In practice the whirling apparatus is securely screwed to the floor of an instrument shelter (see page 398) with the crank shaft projecting through the front of the shelter. The wet bulb and a short length of the stem above are covered with fine, loosely-woven muslin carefully washed to remove the sizing. Pure, clean water is used for wetting, and the muslin renewed whenever it becomes at all dirty.

(b) *Psychrometer for hand whirling*, or the *sling psychrometer*, is mainly used in field work when the whirling apparatus is not available. As shown in Fig. 42 the two thermometers, similar to those used with the whirling apparatus, are mounted parallel and near together on an aluminum back. By means of the handle and attached linkage the thermometers may be whirled at the desired rate. To obtain thoroughly accurate readings the instrument should be whirled in the shade, and the observer face the wind so as to avoid temperature effects due to the heat of his body.

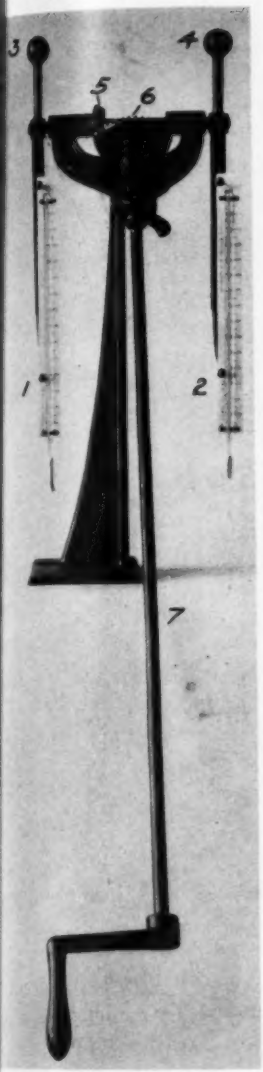


FIG. 41 *Whirling apparatus for wet and dry-bulb psychrometers.*

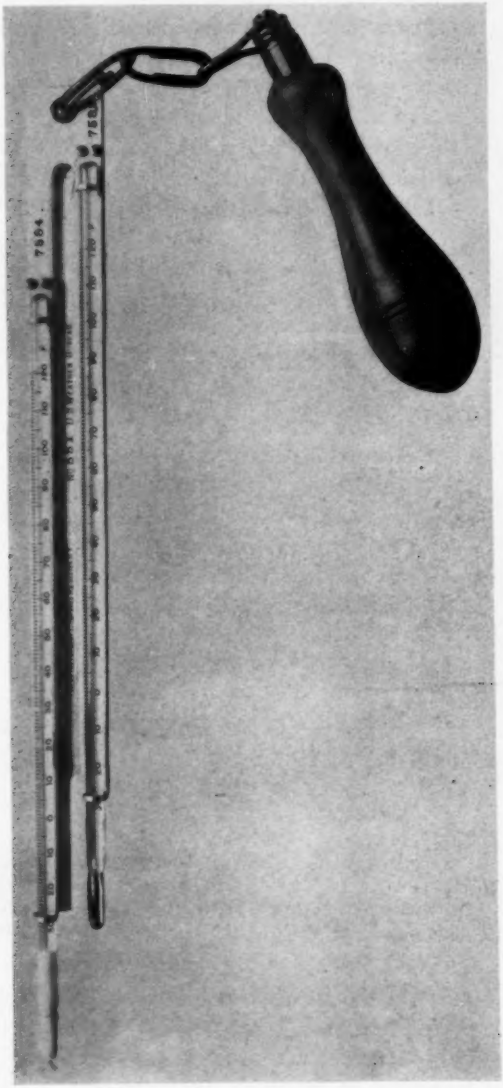


FIG. 42 *Sling psychrometer.*

(c) *Assmann's psychrometer*, Fig. 43, also called an aspiration psychrometer, was invented by Prof. R. Assmann, Germany, in 1886. A number of the instruments have had limited use since 1895, mainly in the experimental field work of the bureau.

Referring to the figure:—Two accurate stem-graduated mercurial thermometers, (1) and (2), are mounted side by side with their bulbs enclosed in double-walled tubes or shields (3), nickel-plated and polished. A clock-driven fan within the top (4) draws air upward

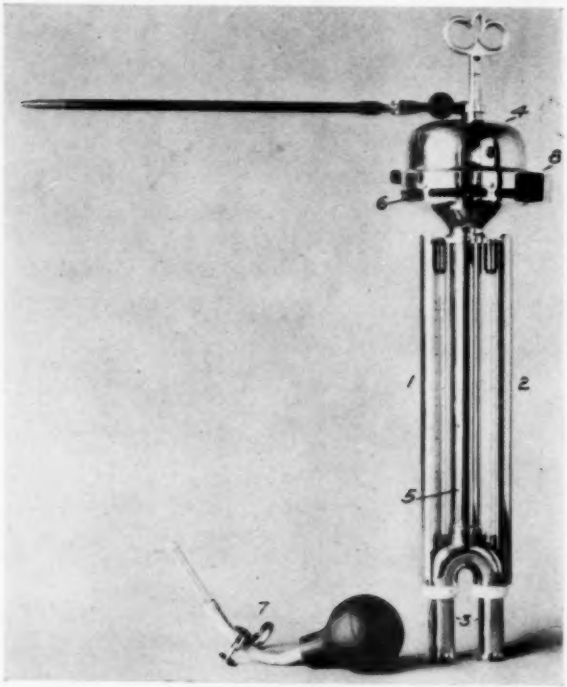


FIG. 43 *Assmann aspiration psychrometer.*

past the bulbs of both thermometers into the central tube (5) whence it circulates to the outlets (6) at the base of the fan chamber. The wet bulb is covered with muslin in the usual way, but is wet with the device shown at (7), which consists of a rubber bulb partly filled with water, having a stem into which a glass tube fits. The pinch cock on the stem s released and water forced into the tube to an index line near its top. The cock is then closed and the water-filled tube inserted as far as

possible into the shield surrounding the wet bulb. When the muslin is thoroughly moistened, the pinch cock is opened, and the tube withdrawn.

The polished bulb-shields effectually protect the thermometers against lateral radiation, so that readings may be made in bright sunshine, provided reflected radiation from below is avoided and ordinary precautions are taken to prevent other temperature errors. When the wind is light and the sunshine strong the instrument must be exposed to the windward of its support, and in strong winds a shield, (8), attached to the windward side of the air outlet at the base of the fan.

2. HAIR HYGROMETERS

The use of the hygroscopic human hair, freed from all oily substance, as an absorption hygrometer, is attributed to Saussure whose instrument appeared in 1780. A single hair was first employed; in later forms, a bundle of hairs, but all of them were designed so that the lengthening

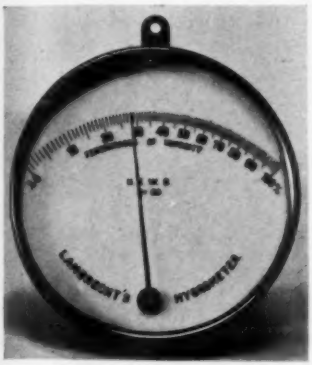


FIG. 44 *Hair hygrometer, Lambrecht's.*

FIG. 45 *Hair hygrometer, Marvin's.*

or shortening of the hair produced rotation of an index over a scale of relative humidity, the hair shortening when it became dry, and vice versa.

Hygrometers have been used for public display purposes by the bureau since the early nineties, and at the present time each street instrument shelter is equipped with one of Lambrecht's make illustrated in Fig. 44, or the type shown in Fig. 45 designed by Prof. C. F. Marvin in 1908. Referring to Fig. 44, a bundle of twelve hairs about 3 1/4 inches long is attached to a weighted lever arm through which rotation of the axis carrying the hand or index is produced, the weight serving to

take up the slack in the hairs and lever. The other end of the bundle of hairs is attached to an adjustable arm by means of which the instrument may readily be set to approximately agree with the wet and dry-bulb psychrometer. The Marvin instrument has a double system of hairs and a dial scale of equal parts. An adjustment for range is also provided.

Experiments conducted by Dr. Ezer Griffiths of the National Physical Laboratory, England, and reported in the Proceedings of the Physical Society of London show the following:

(1) That under normal working conditions and subjected to ordinary variations of humidity and temperature, the hair hygrometer shows a tendency to give high readings with lapse of time. This is due to the hairs taking a permanent set; they must be protected against undue strain.

(2) The instrument should not be subjected to large variations of temperature, and the calibration should be checked at frequent intervals under conditions identical with those under which it is used.

The need for maintaining the hairs and the delicate linkage in a state of cleanliness, is essential to continued accuracy.

3. HAIR HYGROGRAPHS

These instruments are a development of the hair hygrometer, the expansion and contraction of a bundle of hairs causing the motion of a pen across a record sheet with a scale of equal parts ranging from zero to 100 per cent of relative humidity.

The type of hygrograph illustrated was invented by Jules Richard, of France, in 1884, and the first one was placed in service in the bureau in 1892. Like the thermograph and barograph, they serve to give the continuous record so essential for climatic studies.

Referring to Fig. 46:—The lengthening and shortening of the bundle of hairs, (1), passed through the hook on lever arm (2), moves the latter to the left or right respectively, producing rotation of the spindle (3). This in turn moves the lever arm (4) counter-weighted at its outer end and so shaped with respect to piece (5) attached to the pen arm axis carried by post (6) as to produce motion of the pen arm (7) over a relative humidity chart graduated with a scale of equal parts from 0 to 100 per cent.

Adjustment of the pen on the record sheet to the current relative humidity, as found from a reading of the wet and dry-bulb psychrometer, is made at (8), the turning of the thumb screw thus increasing or

decreasing the distance between the hair supports (9) and (10). Range adjustment is provided at (11), and the pressure of the pen on the record sheet at (12). The pen is entirely removed from contact with the sheet by the bell-crank lever (13) which moves the upright bar (14). Record cylinder (15) is rotated by an 8-day clock, a seven-day record being secured.

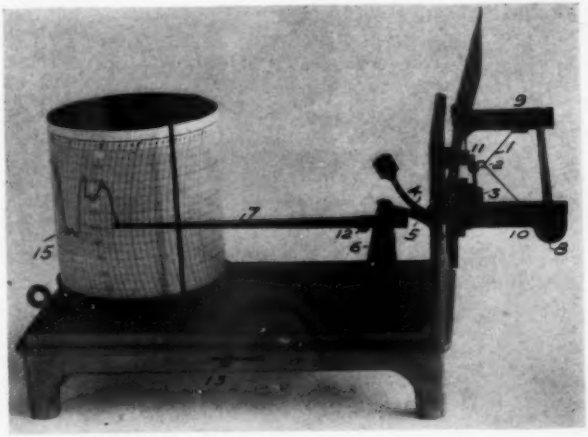


FIG. 46 *Hair hygrograph.*

VI. INSTRUMENTS FOR MEASURING; (1) SOLAR RADIATION; (2) NOCTURNAL RADIATION; (3) SKY BRIGHTNESS; (4) SKY POLARIZATION; (5) ATMOSPHERIC DUST

1. PYRHELIOMETERS

Pyrheliometers measure or record the heat intensity of solar radiation, measurements being finally expressed in gram calories per sq. cm. per min. received by a small area normally exposed to the sun's rays at the earth's surface for direct radiation or horizontally exposed for total radiation.

The pyrheliometric work of the bureau dates from 1901 when several of Angström's compensated instruments were purchased.

In 1910 the Marvin pyrheliometer was introduced, its observations being compared with both the Ångström and the Smithsonian silver-disc pyrheliometers. The latter is in use at present as a secondary standard, the primary standard being Abbot and Fowle's water-flow pyrheliometer. A Callendar recording pyrheliometer was secured in

1908, followed by three more in 1911 and 1912. Some of the Callendar recorders are still in service but they are now being replaced by the newly-developed thermo-electric recorder.

The last of the Ångström pyrheliometers was displaced by the more easily operated Marvin instrument in 1914. While the readings of the latter are corrected to agree with the substandard Smithsonian, silver-disc pyrheliometer, investigations conducted by Dr. Paul D. Foote of

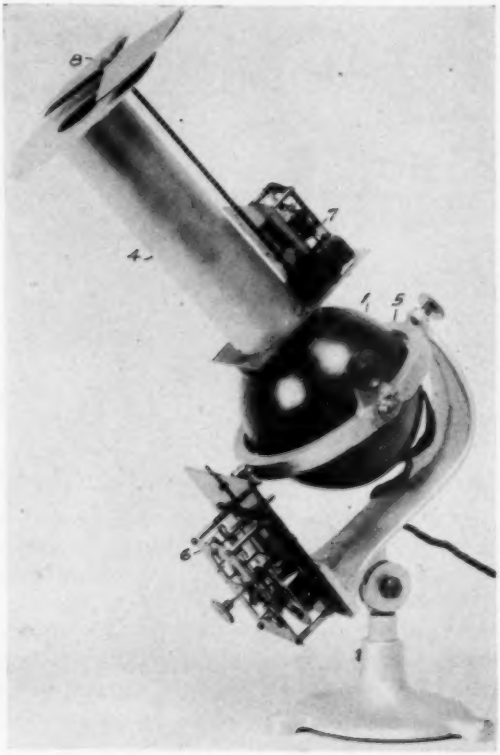


FIG. 47 (a) *Marvin pyrheliometer.*

the Bureau of Standards show that the Marvin pyrheliometer can also be employed as a standard when calibrated by electrical and radiometric methods. Its readings were found to be only 2 per cent lower than those obtained with a Smithsonian substandard with which it was compared by solar radiation observations. This difference of values was stated to be within the errors of observation of the calibration.

(a) *Marvin pyrheliometers*, Fig. 47 (a), are in use at four widely separated representative stations in the United States. The wooden shell (1) contains the silver disc (2) shown seperately in Fig. 47 (b). The disc, which is about 4.5 cm. in diameter and 0.3 cm. thick, is mounted in a metal sheel (3) built in two parts, as is also the enclosing wooden shell, to provide access to the disc. Embedded in an annular recess within the disc is a coil of insulated nickel wire of about 25 ohms resistance wound non-inductively in the form of a flat spiral. This temperature-resistance coil is in firm contact with the silver although well insulated therefrom, while the wooden shell protects the disc from

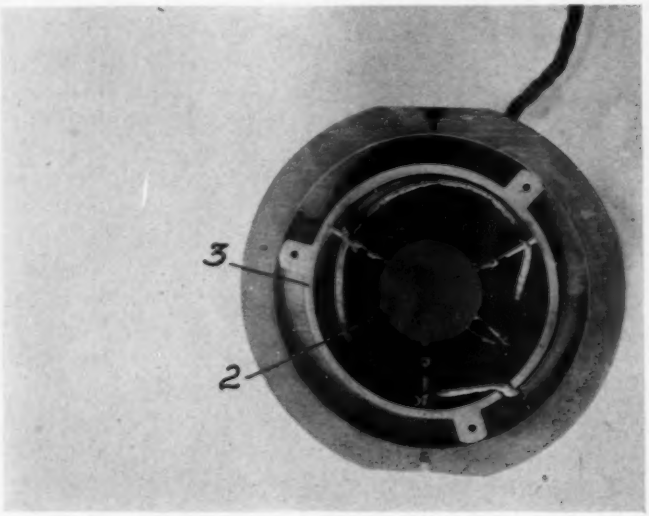


FIG. 47 (b) *Thermal element of Marvin pyrheliometer.*

local temperature changes. The upper surface of the disc is blackened to absorb the heat from a beam of the sun's rays of known area admitted through the diaphragmed tube (4) also blackened within. An equatorial mounting (5) of the tube is provided, driven by the clock (6) through suitable gearing. Clock train (7), together with an electromagnetic release, operates the shutter (8), the magnet being connected with a timing clock (not shown), which closes the circuit each minute.

The operation of the instrument is as follows:—Beginning with the opening of the shutter, when the heating of the thermal element in the disc begins, the increase in resistance is measured over a 50-second in-

terval after a preliminary heating during ten seconds. The shutter then closes, cutting off the sun's rays. and after ten seconds of cooling the fall in resistance over a corresponding 50-second period is measured. These changes in resistance are afterward converted into changes in temperature, and finally into units of heat, the thermal element having previously been calibrated, electrically, by finding (1) the rise in temperature of the coil and disc resulting from the dissipation of a measured

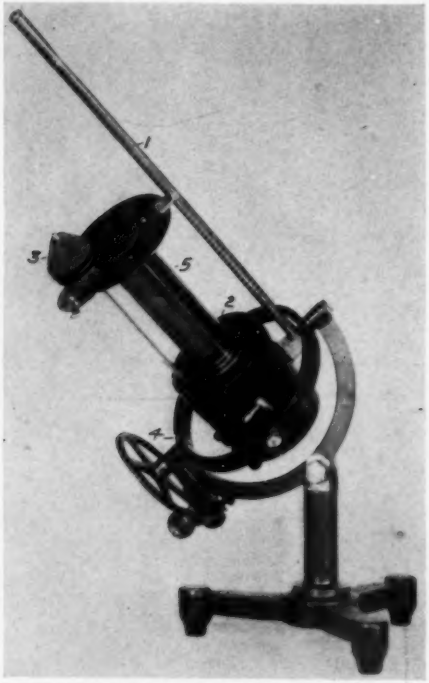


FIG. 48 *Smithsonian silver-disc pyrheliometer.*

quantity of electrical energy, and, (2), finding the resistance of the coil at certain known temperatures. A high-sensitivity galvanometer and a special Wheatstone bridge are included in the auxiliary apparatus for regular observations.

(b) *The Smithsonian silver-disc pyrheliometer*, Fig. 48, was invented about 1902 by Messrs. Abbot and Fowle of the Astrophysical Observatory of the Smithsonian Institution, and one placed in service in the Weather Bureau in 1910. In this instrument the rise and fall of temperature during the heating and cooling

periods of the silver disc are measured direct by a thermometer (1). The bulb of the thermometer is embedded in a hole drilled radially in the disc, the hole being lined with steel and the space between the cylindrical bulb and the steel bushing filled with mercury to facilitate heat conduction. The loss of the mercury is prevented by a soft cord soaked in shellac pressed into the mouth of the hole about the stem of the thermometer. The thermometer tube is bent into a right angle near the point of emergence from the wooden cylinder (2) and enclosed in a brass tube for protection against breakage. Shutter (3) and the equatorial mounting (4) are hand operated. Within the wooden insulating cylinder (2) is a cylindrical copper box carrying a three-point mounting for the disc. The diameter of the beam of sunlight directed on to the surface of the blackened disc, as in the Marvin instrument, is limited by diaphragms within the tube (5). A screen not shown is used to shade the wooden cylinder (2).

Observations with the instrument are conducted as with the Marvin pyrheliometer, excepting that the preliminary heating and cooling periods after the opening and closing of the shutter, respectively, are twenty seconds instead of ten, while the period of observation is 100 seconds instead of 50, the temperature being noted at the beginning and ending of each heating and cooling period. The relation of these temperature readings to the rate at which heat is received and lost is previously determined by a calibration of the instrument against the standard Smithsonian water-flow pyrheliometer.

(c) *Callendar pyrheliometers.*—Callendar pyrheliometers for recording the total intensity of radiation received by a horizontal surface, were the invention of H. S. Callendar, England, first appearing in 1898, and followed by an improved model in 1905. Fig. 49 shows the receiving portion. It consists of an air tight glass cover (1), hemispherical in shape, within which is a differential platinum resistance thermometer (2). Two coils having equal resistance at the same temperature in the dark are wound on horizontally mounted strips of mica, one coil to each strip. One coil (a) is coated with a black glass enamel, while the other (b) is left bright. The blackened coil is joined in series in one arm of a recording Wheatstone bridge and the other connected into the opposite arm. The recorder is pictured in Fig. 50. Standardization of the instrument is accomplished by comparing its readings with those obtained by another recorder the connected receiver of which has been subjected to radiation of known intensity from an electric lamp. Callendar used a lamp that emitted a radiation of one calorie per square centimeter

FIG. 49 *Callendar recording pyrheliometer, receiving portion.*

FIG. 50 *Callendar recorder.*

per minute at a distance of 20 cm., the voltage applied to the lamp being 80.

When heated by radiation the temperature of the blackened thermometer coils becomes greater than that of the bright, the difference in temperature according to Callendar being very nearly proportional to the intensity of the radiation to which they are subjected. The recording Wheatstone bridge registers this difference.

The Callendar pyrheliometer was standardized in 1913 by Prof. H. H. Kimball of the Weather Bureau, by comparison with the Marvin pyrheliometer. It was found that before its indications could be accurately expressed in heat units, the Callendar record must be corrected for the intensity of radiation, the wave length of the radiant energy, (the absorption by the glass cover varying with each receiver), and the temperature of the resistance coils in the receiver. General equations were developed for the reduction of the records.

(d) *Thermoelectric pyrheliometers*, like the Callendar instrument, furnish a record of the total intensity of solar radiation received by a horizontal surface. The idea of employing a thermopile in connection with the measurement of the intensity of solar radiation originated with Ångström in 1886. He used it, however, when connected to a sensitive galvanometer, to indicate the establishment of equality in temperature of two blackened strips of manganin, one exposed to direct solar radiation, and the other strip screened, but heated by passing through it an electric current. The radiation in gram calories per second per cm^2 may then be obtained by equating the radiant energy to the measured electrical energy. The Smithsonian pyranometer belongs in this class, and recently a thermo-electric instrument recording photographically, in use at the Davos-Physical-Meteorological Observatory of Switzerland, was described by C. Dorno in the Monthly Weather Review.

In the recorder under consideration, however, a thermopile of 50 couples (see Figs. 51 (a) and (b)), is employed to generate current of sufficient strength to operate a sensitive recording voltmeter of the *R* 1 Engelhard type. Referring to Fig. 51 (b), the alternate junctions of the thermopile are attached to, but at the same time electrically insulated from, the under surfaces of two thin concentric copper rings, (1) and (2). The inner ring (1) has its upper surface painted black, while the outer (2) is white. A glass cover (3) protects the interior from rain and wind. The wire for the thermocouples is 0.0016 of an inch diameter, the alternate wires of 60% Au −40% Pd, and 90% Pt

FIG. 51 (a) *Thermoelectric pyrheliometer, receiving portion.*

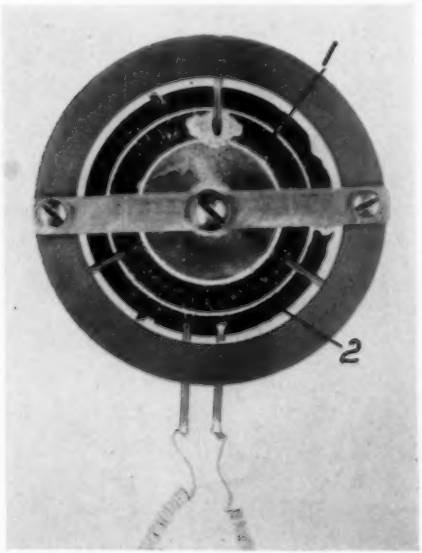


FIG. 51 (b) *Thermopile of thermoelectric pyrheliometer.*

–10% Rh, the junctions electrically fused. It has been found that the excess in temperature of the black ring over the white generates a current the voltage of which is nearly but not strictly proportional to the intensity of solar radiation. Maximum solar intensity generates a current of about 15 millivolts. The records obtained have been checked against observations made with the Marvin pyrheliometer and the scale reading of the record determined. The thermoelectric recorder reads somewhat too low during the middle of the day, but otherwise the factor relating the readings of the two instruments is nearly constant.

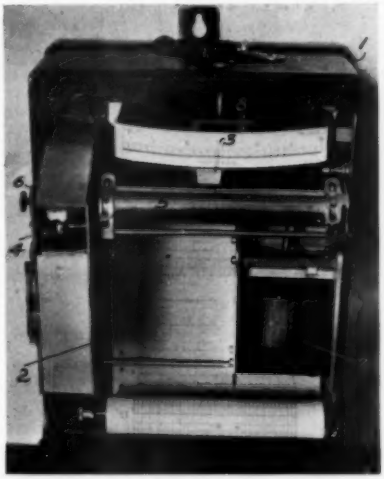


FIG. 52 *Thermoelectric pyrheliometer, recording portion.*

The Engelhard recorder is shown in Fig. 52. There are two compartments in the aluminum case, that to the rear (1) containing the galvanometer system, while the recording mechanism is mounted in the front compartment (2), and protected by a hinged cover omitted in the picture. The galvanometer is of the moving coil type, the coil form-wound and suspended by metal filaments at top and bottom.

The pointer or boom is made of very thin aluminum tubing and in Fig. 52 the outer end is seen at (3). The moving system is "dead beat."

In the case at (4) is a double-spring eight-day clock which is geared to the chart drum (5) through interchangeable gears (6). The chart speed on the Weather Bureau recorders is fixed at $\frac{3}{4}$ of an inch per hour, the width of record is $5\frac{1}{2}$ inches, and the chart rolls 100 feet in length.

An electrical contact is attached to the clock which closes a circuit through an electromagnet (7) once each minute. The electromagnet releases a bar (8) extending crosswise above the pointer, allowing it to fall upon the pointer and during an interval of 20 seconds to press against an inking roller beneath, thus marking the chart on the underside. The chart is semi-transparent so that the record in the form of a series of dots shows through clearly.

A full-scale deflection of the record is produced with a current intensity of 45 microamperes. The thermopile and leads have a resistance of nearly 30 ohms, the galvanometer coils 60 ohms, and in addition there is a fixed resistance of from 150 to 200 ohms in series in the circuit.

2. PYRGEOMETERS

These instruments, introduced into the bureau in 1914, Figs. 53 and 54, are used to measure the intensity of nocturnal radiation from a

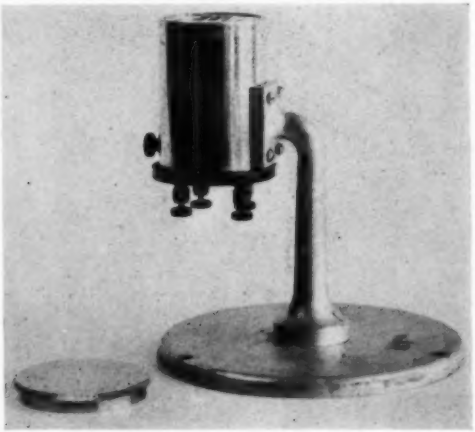


FIG. 53 *Pyrgeometer as used for observations, wiring omitted.*

blackened surface. The design is based on a similar instrument constructed by K. Ångström in 1903. Fig. 54 shows the pyrgeometer with the cover and enclosing cylinder removed. Two of the four thin strips of manganin mounted on the hard rubber block (1) at the top of the instrument are blackened and exposed to the clear or partly clouded night sky. The other two strips, alternating in position with the blackened ones, are gold plated and kept bright so as to reduce radiation to a minimum. Radiation produces a lowering of the temperature of

the black strips relative to the bright ones, which difference is indicated by a thermopile of ten warm and ten cold junctions attached respectively to the under sides of the bright and black strips and joined in series with a sensitive galvanometer. The rate at which the black strips are losing heat, or the intensity of outgoing radiation, is found by sending a heating current through the black strips until the galvanometer shows no deflection, and measuring the current with a milammeter.

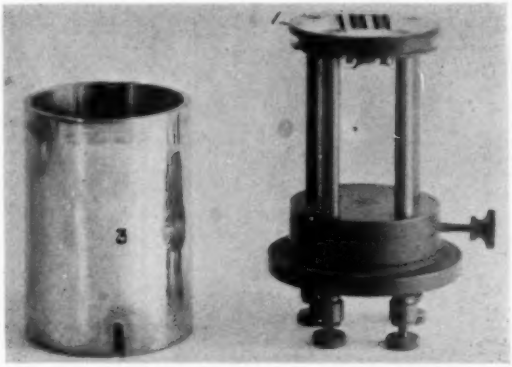


FIG. 54 *Pyrgeometer with cover and enclosing cylinder removed.*

The equation expressing the relation of radiation to the heating current passed through the cooled black strips is as follows:

$$R = Ki^2,$$

R being the radiation in gram calories per cm^2 per minute, i, the current intensity in amperes, and K a constant depending upon the dimensions and electrical resistances of the strips. The constant K, determined experimentally, was found to be nearly 9.7.

3. PHOTOMETERS

Sharp-Millar photometers have been used by the bureau at intervals since 1913 to measure the daylight illumination in foot-candles on a horizontal surface freely exposed to the sky, including that portion of it occupied by the sun, or to the sky alone with the sun artificially eclipsed. Measurements of sky brightness have also been made.

Referring to Fig. 55: (cover open to show the interior). At the end of the elbow tube (1) a test plate of translucent glass is horizontally exposed for illumination tests, its upper surface ground to prevent

regular reflection. The daylight producing the illumination is reflected by a mirror in the angle tube and directed on to a modified Lummer-Brodhun prism set within the box opposite the sighting tube (2). Through the latter the daylight illumination is compared with that produced by the comparison lamp. Light from the lamp chamber reaches a small window of milk glass near the prisms, passing thence to the prisms, where it is reflected to the observer's eye alongside the light received from the surface illuminated by daylight. The intensity of the illumination produced by the 6-volt Mazda comparison lamp is varied by adjusting its distance from the window by means of the knob (3), the turning of which actuates a cord drive to slide the lamp support endwise through the box. When equality of illumination is reached, the

FIG. 55 *Sharp-Millar photometer used for observations of daylight illumination and sky brightness.*

position of the lamp is read from a scale (4), and this scale reading is reduced to foot-candles of illumination by the use of factors determined by standardization tests. Adjustment of the lamp current is affected at (5).

Some modifications of the use of the instrument as above outlined have been necessary in Weather Bureau work in order to measure illumination of great intensity, and to make the illuminations comparable as to color. In addition to the two neutral glass screens provided by the maker of the instrument, which transmit about 10% and 1% of the daylight respectively, the light is also passed as a rule through a milk-glass screen in addition to one of the neutral screens. Two blue-glass screens are used to change the color of the comparison light to match the daylight as a whole, or that coming from the sky alone. The blue-glass screens are of course interposed between the window in the lamp chamber and the prisms; the others in various combinations between

the prisms and the test plate. In some cases a yellow filter has taken the place of the milk-glass screen, and the blue-glass screens have been omitted.

In practice, the photometer as a whole is mounted on a revolving support, so that the angle tube may be directed toward any portion of the sky to measure its brightness. When this is done the test plate is removed.

The total mid-day illumination with a clear sky on a horizontal surface has been found to be as great as 10 000 foot-candles. Twilight illumination falls to less than 1 foot-candle when the sun is about 6 degrees below the horizon.

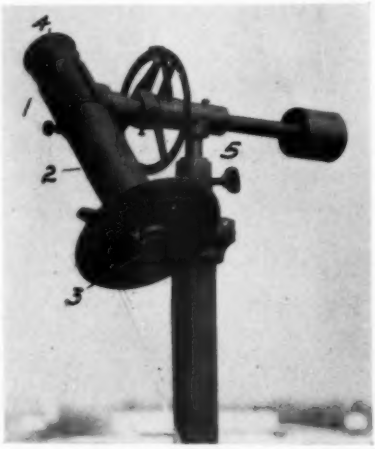


FIG. 56 *Polarimeter.*

4. POLARIMETERS

This instrument, designed and used by Edward C. Pickering in 1885, is illustrated in Fig. 56. It has a limited use in solar radiation investigations, and observations of sky-light polarization have been made since 1902.

Within the lower half of tube (1), approximately at (2), and adjustable in position along the axis, is an Iceland spar crystal so placed as to give a double image. At the eyepiece, (3), is a Nicol prism or analyzer, which is turned about the axis of the tube until the two images are brought to equal brightness, or one of them is eliminated, a series of grids across the end of the tube at (4) permitting of this result.

The tube (1) is adjusted in altitude and azimuth by means of support (5). When an observation of polarization is to be taken, the tube is pointed 90 degrees from the sun in its vertical circle, then the analyzer (3) is turned until a uniform blue field shows, and the grids disappear from sight. There are four points in the circle where the field is of uniform intensity, and the angular distance between these points is a measure of the skylight polarization.

In the absence of dust, the light is scattered by gas molecules, producing a maximum of polarization; when dust is present in the atmosphere, the particles of which are relatively large, they cause diffuse reflection and a consequent lessening of polarization.

5. OWEN'S DUST COUNTERS

The dust content of the atmosphere has been under measurement at Washington, D. C., and occasionally at other places in the United States since December, 1922, as a part of a program of international cooperation organized under the auspices of the meteorological section of the International Union of Geodosy and Geophysics. An instrument designed by Dr. J. S. Owens of London, illustrated in Fig. 57, is in use.

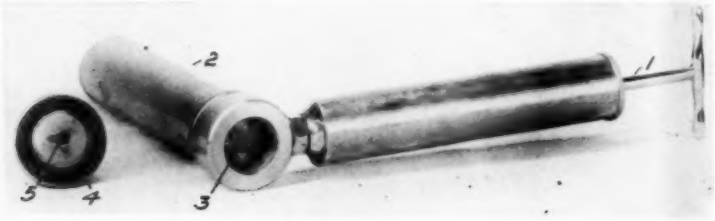


FIG. 57 *Owen's dust counter.*

Referring to the figure: When it is desired to measure the dust content of the air, the plunger of the pump (1) is pulled out one or more full strokes, bringing a sample of the outside air into the tube (2) where it is moistened by a lining of blotting paper saturated with water. From this tube the moist air with its dust content passes at high velocity through a narrow slot (3) into a small chamber which is closed by cap (4) by means of a three-claw spring (5). The reduction of the pressure of the air while it is passing through the slot causes the condensation of moisture upon the dust particles, which, as a result, stick to the cover glass when they strike it. The glass is withdrawn, the moisture quickly evaporating as a rule, and at a convenient time the dust particles adher-

ing to the glass are counted under a high-powered microscope, and the number per cubic centimeter of air estimated. A microscope magnifying to as great as 1500 diameters is sometimes employed, but usually 1000 diameters magnification is sufficient.

The bureau's solar radiation observatory at the American University in the outlying suburbs of Washington found an average of 850 particles per cm.^{3} in winter, and 400 during summer, with extremes ranging from 4000 to 100.

Knowledge of the dust content of the atmosphere is particularly useful in studies of visibility, especially in connection with aerial navigation. Roughly stated, the limit of visibility in miles is equal to a constant, about 480,000, divided by the number of dust particles per cm^3, multiplied by the percentage of relative humidity, provided fog is not present in the atmosphere.

VIII. INSTRUMENTS FOR MEASURING EVAPORATION

Data giving the rate and quantity of evaporation find practical application in various ways. The engineer is often much concerned, particularly in hydro-electric and irrigation projects, in determining evaporation losses from watersheds and reservoirs in connection with the rainfall and runoff; and the plant physiologist makes a study of losses from foliage, etc. Prospective farmers in the western states, where either dry farming or irrigation are necessary, should examine records of evaporation as well as those of temperature and rainfall.

A complex relation exists between the rate of evaporation and the controlling elements of temperature, wind velocity, vapor pressure over a free water surface, etc., and while many efforts have been made to correllate these relations mathematically, so as to be able to compute evaporation when the climatic factors are known, such efforts have in general been unfruitful. A study of evaporation intended to determine its law under certain defined conditions, involves the most careful and precise measurement of all the controlling factors. At present the bureau is confining its work at certain selected stations to daily observations of the amount of evaporation from galvanized pans 10 inches deep and 4 feet in diameter similarly exposed, and filled to the same depth with water. One of these so-called Class A stations is illustrated in Fig. 58. The measured depths of evaporation in inches and thousandths of an inch are comparable only with each other; i.e., they are relative values. To connect the evaporation from such a pan with that occurring from lake, reservoir, or other evaporating body, is another problem, but the depths

measured enable us to follow the progressive changes, and to study the climatic aspects of evaporation. Observations of evaporation are accompanied by those of the daily wind movement over the pan as shown by a cup anemometer, and by rainfall and temperature measured nearby. (See Fig. 58) For the evaporation measurements themselves, in addition to the pan already described, only the stillwell and hook gage need be mentioned, as follows:

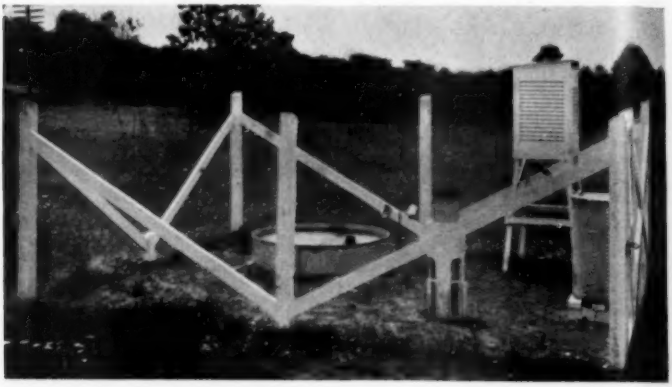


FIG. 58 *Fully-equipped Class A evaporation station.*

1. STILLWELL

This device, designed by B. C. Kadel, was introduced in 1914 at the time of the inauguration of the Class A evaporation stations. Fig. 59 shows the stillwell and hook gage mounted in reading position. The whole assembly is placed in the 4-foot pan containing water about 8 inches deep, the stillwell resting on the three-inch levelling screws (1) in each corner of the cast-iron base (2), which measures ½ inch in thickness and 12 inches on each side. Screwed to the base by the flange (3) is a seamless brass tube 8 inches high and 3½ inches outside diameter. Water flows into the well through a small pipe in the center of the base, thus providing a quiet surface to permit of accurate measurements with the hook gage.

2. HOOK GAGES

Two other types of hook gage besides the one illustrated in Fig. 60 are in use, but they are all similar in having a hook (1), the point of which is first immersed in the water in the stillwell, then gradually raised until it just causes a slight depression in the water surface but

does not puncture the surface. The height is then read by reference to the scale on the casing (2) and the micrometer screw head (3), each complete revolution of the head moving the hook vertically one-tenth of an inch. Inches and tenths are graduated on the casing, and hundredths and thousandths are read from the micrometer. The manner of mounting the hook gage on the stillwell is obvious from Fig. 59.

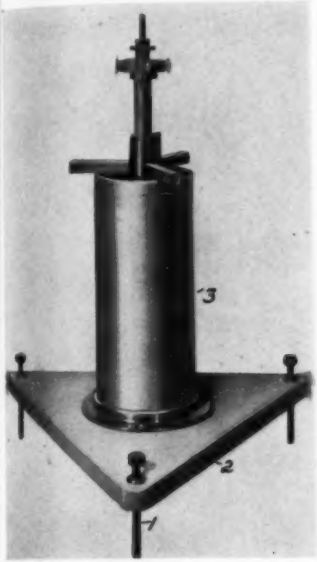


FIG. 59 *Evaporation still-well with hook gage mounted in reading position.*

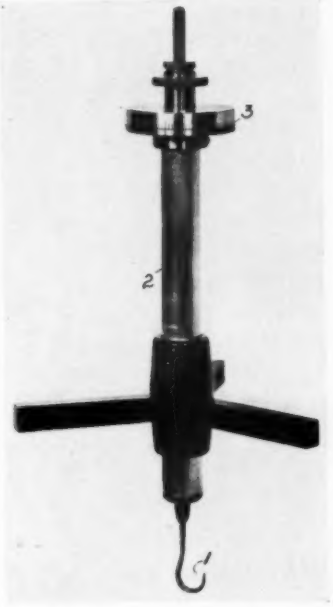


FIG. 60 *Evaporation hook gage.*

IX. REGISTERS OF WIND VELOCITY AND DIRECTION, SUNSHINE, AND RAINFALL

The registers and recorders here described are all electrically operated and connected with instruments suitably exposed out-of-doors, the register itself being conveniently located in the office. There are three registers in this group: first, the single register, ordinarily used to record wind velocity, but which can be adapted to rainfall registration instead; second, the double register for wind velocity and rainfall; and third, the quadruple register (also called triple register) by means of which wind direction and velocity, duration of sunshine, and depth of

rainfall are recorded on one sheet. Thermometric sunshine recorders, tipping-bucket rain gages, Robinson anemometers, and recording wind vanes, all of which have been described, are used in connection with one or all of these registers.

1. SINGLE REGISTERS

Single registers, designed by Lieut. D. J. Gibbon, Fig. 61, were first employed in 1871 in essentially the form shown. The registers were improved by Prof. C. F. Marvin, the present-used type appearing about 1898. Referring to the figure: The metal cylinder (1) carrying the record sheet is revolved once each six hours by the clock (2), the axes of clock and cylinder being joined by sliding yoke (3) and universal joint (4), which permit of a lengthwise motion of the cylinder by means of the steep screw (5), the latter threading into post (6). The record therefore takes the form of a spiral starting at the end of the cylinder farthest from the clock. An electromagnet is connected in series with a low-voltage battery and the anemometer contacts, and upon closure of the circuit at the end of each mile of wind movement, the magnet is energized, causing the pen (7) to make a short lateral offset. When the circuit is broken the armature is pulled back to its original position by a spring. Knowing the length of time required for the passage of one or more miles of wind past the anemometer, the velocity is readily computed.

2. DOUBLE REGISTERS

This register, also called the two-magnet register, is similar to the single register, excepting for the addition of another magnet and a clock contact by means of which either the rainfall or sunshine, or both, is recorded besides the wind velocity, as described more fully below under quadruple registers. The additional magnet is seen at (1) in Fig. 62. This register was introduced into the service in 1897 by Prof. C. F. Marvin.

3. QUADRUPLE REGISTERS

The quadruple register was developed by Prof. C. F. Marvin and others, and brought into use in 1888, being first employed for wind direction and velocity and rainfall. The registration of sunshine was included in 1893, when the mercurial sunshine recorder (Fig. 38) was invented. Since 1896, however, practically no changes have been made to date (1924). Each first-class station of the bureau is equipped with one of these registers.

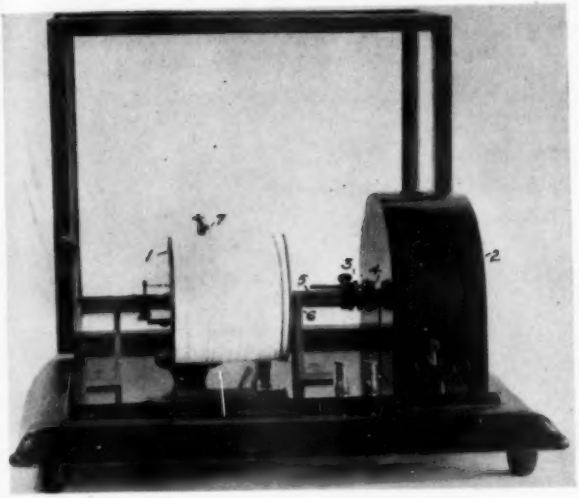


FIG. 61 *Single register for recording wind velocity with a Robinson anemometer.*

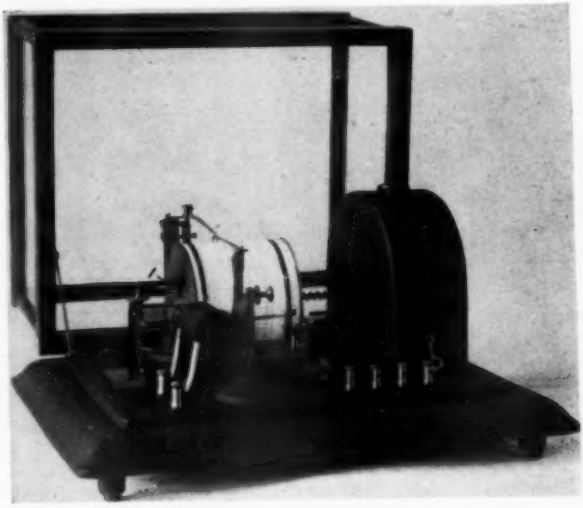


FIG. 62 *Double register for recording wind velocity, rainfall and sunshine.*

Referring to Figs. 63 and 64: The wind-velocity recording mechanism (1) is essentially the same as that used in the single and double registers. The clock and the connections for driving the cylinder are likewise nearly the same, excepting that a steep screw (2) is used which produces a lengthwise motion of the cylinder (3) of half an inch for each six-hour revolution of the latter. The cylinder is nearly $4\frac{3}{4}$ inches in diameter and 5 inches long.

Four magnets (4) are used to record wind direction, one for each cardinal point, but the wind-vane contacts (see Fig. 21) are so arranged that the four intermediate directions are recorded, when two magnets corresponding to adjacent cardinal points are energized at once, for example north and east. Each armature (5) carries a long brass arm (6) with a steel printing point secured to its outer end at (7). The closure of the circuit by the clock causes the printing point to strike the cylinder each minute, thus producing a series of dots passing through letters on the sheet, N, E, S and W, corresponding to the directions from which the wind is blowing. The printing points are inked by rubbing a pivoted ink pad, which is pressed out of the way as the point approaches the cylinder.

The sunshine-rainfall magnet appears at (8) in both figures. For registering sunshine the electric circuit to the magnet, when closed by the recorder, passes through a minute contact in the clock. An open circuit or absence of sunshine gives a straight-line record; sunshine produces a step-by-step record, lateral motion of the pen being accomplished by ratchet and ratchet wheel (9)working in conjunction with a cylindrical cam (10) mounted on the same axis as the ratchet wheel, the cam consisting of a double right and left-handed helical groove in which pin (11) moves. The same device registers rainfall, the clock contact of course being left out of the circuit. Each lateral displacement of the record then corresponds to a fall of 0.01 of an inch of rain. When sunshine and rainfall occur together, the irregular nature of the rainfall record permits of its being picked out from amongst the regular steps of the sunshine record.

X. Instruments and Apparatus Used With Kites and Balloons for Upper-air Meteorological Observations

Aerological research work as a definite program of the bureau began in 1896 with the development of cellular or box kites, together with apparatus for their control in flight, by means of which light-weight meteorographs could be carried into the atmosphere to considerable

heights to obtain records of temperature, pressure, relative humidity, and wind velocity. During 1898 from April to November, kite ascensions were systematically made at 17 stations, but no further work of

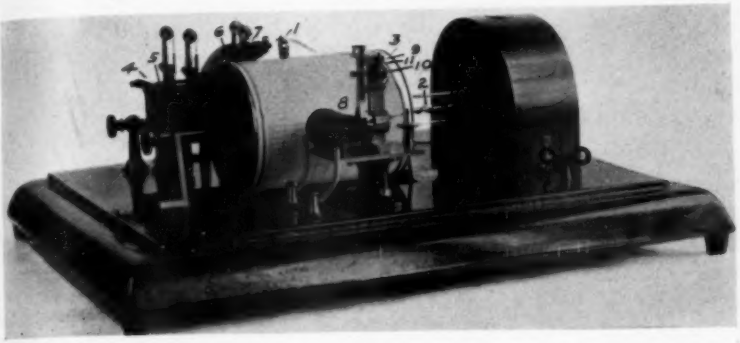


FIG. 63 *Quadruple register for recording wind velocity and direction, sunshine and rainfall. Sunshine and rainfall magnet on near side of cylinder.*

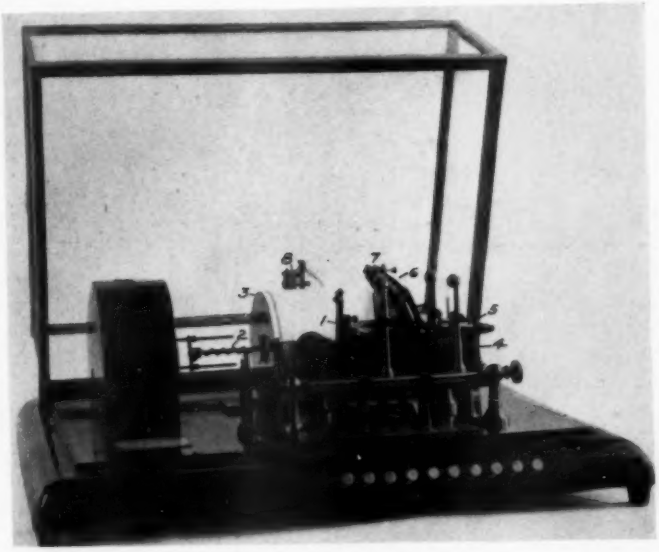


FIG. 64 *Quadruple register showing velocity and direction magnets.*

consequence along these lines was accomplished until the observatory at Mt. Weather, Va., in the Blue Ridge Mountains west of Washington,

D. C., was opened in 1907. All the upper-air work was concentrated there until 1914, excepting for an occasional series of sounding-balloon observations made in the central and western states. Captive balloons were employed at times at Mt. Weather in addition to the kites. The work was transferred from Mt. Weather to Drexel, Neb., in 1915. This was the bureau's only aerological station until the entry of the United States into the World War, when five additional stations were established in 1918, mostly in the Great Plains region, in order to better cooperate with the Signal Corps of the Army in aeronautics. All six stations have been in continuous operation since.

Daily observations with kites are conducted whenever possible, and about twice each month a succession of flights of sufficient duration is made to determine the diurnal changes in the meteorological elements at different altitudes. In addition there are twice-daily observations with theodolites of pilot balloons at each of the six kite stations, and also at Washington and Key West, together with one daily pilot-balloon observation at eight other regular Weather Bureau stations. Sounding-balloon observations using the Fergusson meteorograph have not as yet been undertaken because of lack of funds.

Kite and balloon flights furnish data from which are determined the variation of temperature, pressure, relative humidity, wind direction and velocity with altitude; not only annual, seasonal and monthly mean values, but to a lesser extent diurnal values. Information of this kind, particularly that of current conditions, is essential to forecasting flying weather for aviation, and as an aid to forecasting surface weather as well. All is useful in developing knowledge of the meteorology of the upper or free air.

Each kite station is equipped with the following instruments and apparatus:

(1) Kites of three sizes, but of the same model, suitable for flying in light, moderate and high winds, respectively; (2) kite reel, variable-speed motor and housing; (3) meteorographs; (4) balloons and filling apparatus; (5) theodolites. The complete instrumental equipment of a first-class station is also maintained for observations at the surface, with the addition of a second shelter attached to the reel house (see Fig. 67) within which meteorographs are placed for ten-minute periods before and after flights to determine the temperature and humidity base lines on the record sheets by reference to readings of a whirled psychrometer in the shelter. There is also a dial wind vane in the ceiling of the reel house for occasional observations of the surface wind direc-

tion during flights. Detailed description of the above-named special equipment follows:

1. KITES

Kites were first used in meteorology in 1749 at Glasgow, Scotland, when Wilson and Melvill raised thermometers to considerable heights. The idea of using more than one supporting plane in a device for flying in the air dates from 1866, but the actual construction of a kite along these lines was not accomplished until the decade ending about 1890, when an Australian, Lawrence Hargrave, built cellular kites for aeronautical experiments. However, it was not until 1895 that box kites were first built and used at Blue Hill Meteorological Observatory, Mass., and elsewhere for meteorological purposes following experiments

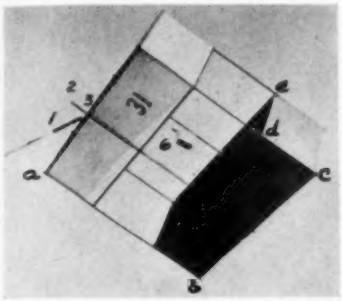


FIG. 65 *Kite in flight showing meterorograph.*

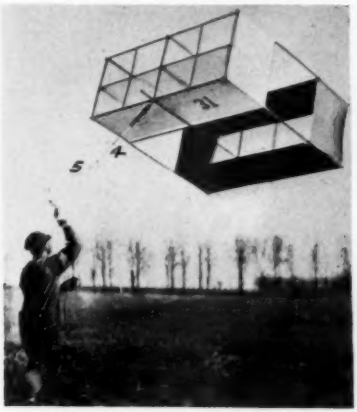


FIG. 66 *Start of a kite flight.*

with ordinary flat kites with tails. In the Weather Bureau preliminary work by S. A. Potter and Alexander G. McAdie in 1895 was succeeded by an intensive study of the box kite by Prof. C. F. Marvin, resulting in a modification of the Hargrave construction which has proved entirely successful and is used practically in its original form now.

Referring to Figs. 65 and 66, the distance fore and aft, (ab), of the standard kite is 6 ft. 8½ in., the dimensions of each cell: length, (bc), 6 ft. 4½ in., height, (cd) 2 ft. 1 in., and width, (de), 2 ft. 8½ in. The upper cell has a middle plane. All sticks forming the framework are made of straight-grained spruce; sticks which are transverse to the wind during flight have rounded edges to reduce resistance to the wind.

Metal angles, partly fastened by bolts, are in addition lashed to the sticks at the joints with waxed thread, and diagonal braces of fine steel wire stiffen the construction. The bridle of the kite, made of cloth-covered rubber, seen at (1), is securely attached to the central stick (called bridle stick) at two places, (2) and (3), by means of stout cords, and another cord, (4), in the form of a double loop carries a brass ring (5) to which the kite wire is secured. The meteorograph is seen at (6) securely lashed to the longitudinal stick opposite the bridle stick, and also guyed by cords. The lifting surfaces are made of Lonsdale cambric or French percaline, both cotton fabrics, their area amounting to 63.8 sq. ft. in the standard kite, the steering or neutral surfaces aggregating 21.7 sq. ft. One cell is made black and the other white in order that the kite may be plainly visible against skies of differing color and brightness. The kite is about 9 pounds in weight, and will fly in

FIG. 67 *Reel house with kite in flight.*

winds ranging from 12 to 30 miles per hour near the ground, 70 miles per hour when two to three miles high. The kites are usually flown in tandem, very seldom singly, and sometimes as many as eight kites are out at once, but ordinarily only three or four are required, the number depending mainly upon the wind velocity, coupled with stratifications of the air currents above the surface. The character of the weather is also an important factor; abrupt changes especially call for skill and judgment in flying kites.

2. KITE REEL AND REEL HOUSE

To properly fly the above-described box kites, a motor-driven reel of rugged construction is required, under complete control at all times,

as can be realized when it is stated that occasionally the length of the steel kite wire to be reeled in may be as great as nine miles. Music wire, ranging between .028 and .044 of an inch in diameter, is usually employed, and the pull of the wire and kites as shown by a dynamometer at the reel may at times be in excess of 300 pounds.

The reel house is shown in Figs. 67 and 68. In Fig. 68 the reel itself is visible through the open door. The house, constructed mostly of wood, is about 15 feet in diameter at the base, with the peak of the roof 15 feet above the ground. An 8-foot doorway, closed by sliding doors, is provided, and the entire house made so as to turn by means of a hand

FIG. 68 *Near view of reel house showing interior.*

apparatus about its vertical axis, so that it may be positioned with reference to the direction taken by the kite wire. The instrument shelter already mentioned with its extra double roof may be seen to the right of the doorway in Fig. 68.

The reel was designed by Prof. C. F. Marvin in 1906, following an earlier one used in the late nineties. It was modified by Maj. Wm. R. Blair about 1908. Referring to the three illustrations, Figs. 69, 70 and 71: The drum, (1) a semi-steel casting, is carried and rotated by two cast-iron wheels or spiders, the throat of the drum upon which the wire is wound being 12 in. wide by 1 inch deep with a diameter of two feet. The outer ends of the shaft carrying the drum are supported in two heavy brackets, (2) and (3). Two brakes, a hand brake (4) and a foot brake (5) are carried on the shaft together with the driven gears (6) and (7), the larger one for slower speeds. These gears remain in mesh with the pinions on the drive shaft, selection being accomplished by

means of a double-throw friction clutch (8), controlled through levers (9) shown in Fig. 69.

Power from a 5 horse-power variable-speed motor (10) is transmitted by means of a chain (11). The motor has a range of speed from 400 to 1800 revolutions per minute, and is controlled by hand-wheel (12).

The kite wire enters the reel over wheel (13), which is mounted so as to turn in a bearing support at (14). The arrangement permits the wheel to follow the changing direction of the wire. The wire passes thence to the wheels in the distributor carriage (15), which is moved

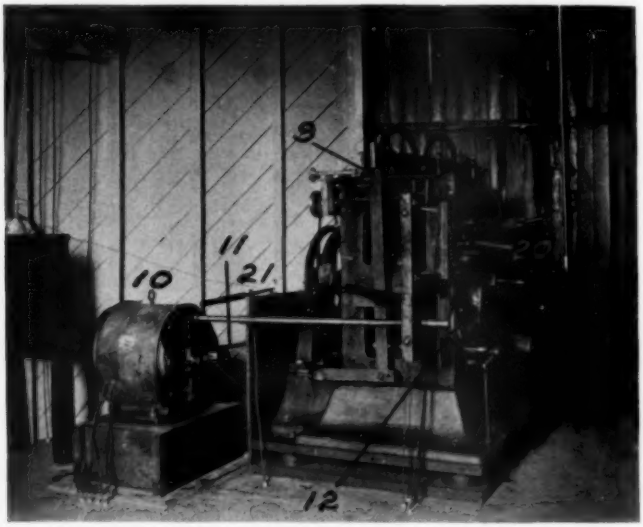
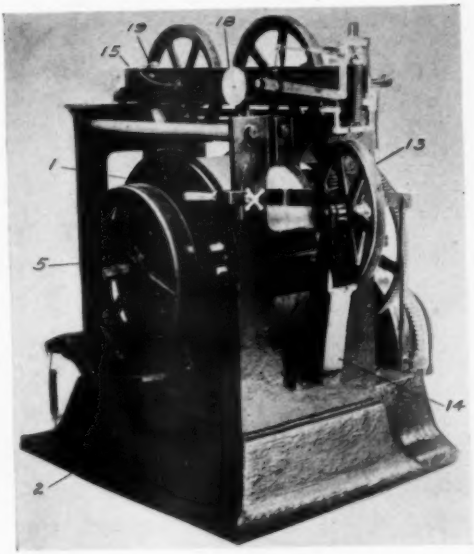
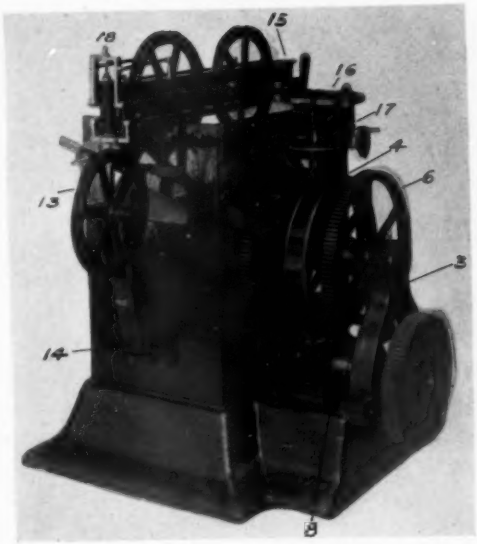


FIG. 69 *Rear of kite reel with motor and apparatus for control.*

back and forth over the drum by means of a cam and attached linkage (16) driven by a worm and worm-wheel (17). The worm shaft is turned by chain and sprocket, power being derived from the main shaft. Auxiliary equipment includes a dynamometer (18), a Veeder counter (19), and a motor-starting rheostat at (20).

It will be noted that the motor is insulated from the floor. At (21), Fig. 69, is a grounding switch, which, when opened, enables the operator to measure the potential of the reel with reference to the earth with a Braun electrometer. This device is used only to warn the kite fliers of approaching thunderstorms.





FIGS. 70 and 71 *Views of reel from front.*

3. METEOROGRAPHS

(a) The *kite meteorograph* of the type shown was designed by Prof. C. F. Marvin and introduced in 1897. It was originally intended to use an electrically recording Robinson cup anemometer of small size in connection with it, but a fan-type anemometer was substituted.

Referring to the illustrations, the complete instrument in its enclosing case of aluminum is shown in Fig. 72, the recording pens being visible through the window near the bottom. Four elements are recorded, namely, wind speed, air temperature, atmospheric pressure, and relative humidity, given in the order from front to rear in which the pens record on the drum in Fig. 73.

Since lightness is essential in an instrument raised by a kite, most of the metal used is aluminum. Bearings and links are made of German-silver, and a few parts in the clock and elsewhere are brass. The anemometer, (1), is placed in the windward end of the aspiration or screening tube (2), which also contains hygrograph hairs and a bimetallic thermograph element. Two aneroid shells of the usual construction are observed at (3); some of more recent make, however, have sylphon elements. The instrument complete with cover weighs 1150 grams, (less than 2½ pounds).

The *anemometer* is of the Assmann type, an eight-bladed fan built along the lines of a Woltmann fly-wheel anemometer. Rotation of the fan turns a small plate cam by means of a train of worm gearing, and the inner end of lever (4), held against the cam by a spring, receives motion through which the pivoted axis (5) is made to revolve through a small angle. Pen-arm (6) attached to the same axis is therefore displaced laterally, once for each 5376 revolutions of the fan wheel. Each instrument is tested and a reduction factor for the record determined at the velocities experienced during kite flights, by comparing its registration with the movement of a standard Robinson cup anemometer during a time interval of three or four hours.

The *pressure element* is quite similar to that of the ordinary aneroid barometer, excepting that two nickel-plated steel vacuum shells (3) are employed with external spring to prevent their collapse under air pressure. There is a simple direct linkage to the pen-arm (7). Compensation for temperature is provided by leaving a little air in one shell, and by using a bimetallic link (8). Adjustment of the scale value is made by altering the length of link (9) by moving it in or out of the pen-arm axis.

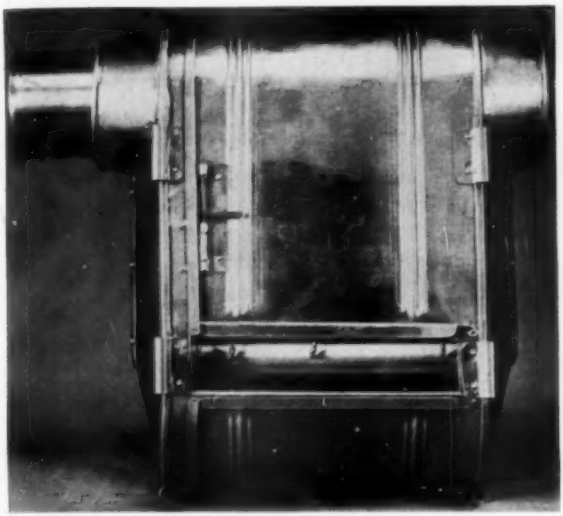


FIG. 72 *Marvin kite meteorograph complete with cover.*

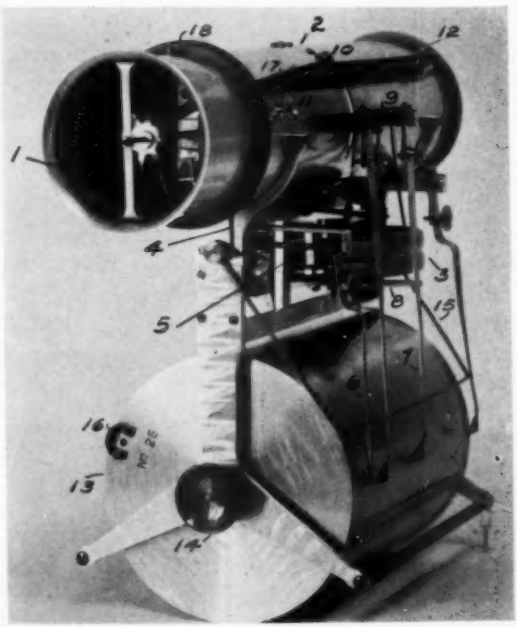


FIG. 73 *Kite meteorograph, cover removed.*

The *temperature element* is a thin bronze-invar bimetallic strip of circular form about 1 5/8 in. in diameter and 1 in. wide. One end of the element is adjustably fixed at (10); the motion of the free end is transmitted by simple linkage to the pen-arm. Pen adjustment is made at (10); scale adjustment by varying the lengths of the pivoted levers in the linkage.

The *humidity element* consists of two groups of eight hairs each, mounted singly instead of in the usual bundles to secure greater sensitivity, and so arranged that their expansion and contraction adds together, producing an effect equivalent to an element 12 5/8 in. long. The movement of the free end of the hairs is communicated to the pen-arm by direct linkage, no attempt being made to correct the motion to a scale of equal parts by the introduction of a cam or other device. (See hygrographs). The true values of the recorded readings are determined by a comparison of each instrument under controlled humidity conditions with a ventilated psychrometer, and from these data a special scale for each is constructed, from which the relative humidities corresponding to recorded values may be read. Adjustment of the pen on the record sheet is made at (11) and (12); the range adjustment is within the screening tube.

Record drum (13) is about 5½ in. long by 3¾ in. in diameter and contains the driving clock, one revolution occurring in eight hours. The clock may be wound by holding the drum and turning thumbnut (14). At (15) is a pen lifter, and the record sheet is secured to the drum by means of a brass spring, the end of which is seen at (16).

Parts (17) and (18) are made of bakelite and serve to insulate the aspiration tube against the heat of the enclosing case.

(b) *Sounding-balloon meteorographs* of the type illustrated in Fig. 74 were designed in 1919 for Weather Bureau work by S. P. Fergusson following an earlier model made in 1905 at Blue Hill Observatory. The first use of balloons for upper-air observations with recording meteorological instruments occurred in 1893, credit being given to two Frenchmen, MM. Hermite and Besançon. They employed balloons made of so-called "gold-beater's skin"; later, silk and paper were used, but it was not until sheet rubber balloons were introduced by Dr. Richard Assmann, the German meteorologist, that the work was placed on a thoroughly practical basis. Following his method a rubber balloon is inflated with hydrogen to a capacity of about 1 cu. meter, a volume sufficient to raise the meteorograph weighing 180 grams, a parachute of 50 grams, and a basket of 45 grams, and leave an excess lift of 500 to

1000 grams, depending mainly upon the rate of ascent desired. The balloon expands as it rises in regions of lower atmospheric pressure until the rubber can no longer withstand the outward pressure of the hydrogen. Then it bursts, and the meteorograph supported by a parachute falls gently to earth, three elements, pressure, temperature and relative humidity being recorded.

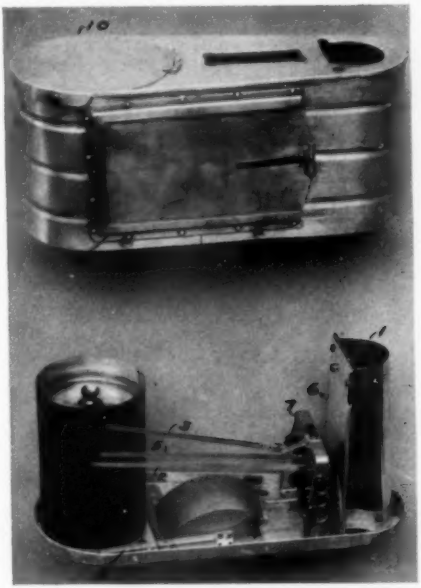


FIG. 74 *Fergusson sounding-balloon meteorograph.*

Referring to Fig. 74, the screening tube (1) contains the temperature and humidity elements connected by simple linkage to the recording pens (2) and (3) respectively. The fixed end of the pressure element (4), an air-exhausted bourdon tube, is attached to the base of the instrument. Its motion is communicated to the pen-arm (5) through a linkage capable of producing two traverses of the record sheet, a relatively slow motion for the first 10 000 meters of ascent, covered by the downward traverse, and one twice as fast for elevations in excess of about 10 000 meters, the rate of change of pressure with elevation being much slower at high elevations.

The temperature element is made of bronze-invar thermo-static metal, 0.2 mm in thickness and 30 mm wide, bent into a circular form of nearly 15 mm diameter, with one end attached to the vertical part (6) of the screening tube and insulated therefrom with a block of bakelite. The scale value is 0.5 mm per degree centigrade.

The humidity element is composed of six (sometimes eight strands of three hairs each about 85 mm long, the upper ends attached to a fixed block near the upper end of the aspiration tube, the lower ends secured to the free end of a flat phosphor-bronze spring which keeps the hairs in tension.

FIG. 75 *Sounding balloon and meteorograph ready for flight.*

The arms carrying the record-markers or stylii all have the same radius, and are mounted on steel pivots in the support (7). At (8) a fixed marker traces a base line or axis from which the vertical ordinates of the traces are measured. The clock drum, 80 mm high and 57 mm diameter, revolves once per hour, the clock being wound by rotating the drum anti-clockwise a number of turns corresponding to the probable number of hours elapsing before the meteorograph will reach the ground again. Record sheets are made of thin, hard sheet aluminum

(.03 mm) coated with lamp-black, and secured to the record drum by means of a lock joint. The tracing points or stylii are made of phosphor-bronze.

When ready for an ascension the covered instrument is fastened securely to a wicker basket, which in turn is secured to the balloon by stout cords. Over the inflated balloon is a parachute of the usual construction. (See Fig. 75)

The cover, shown separately in Fig. 74, is made of thin sheet aluminum with an opening (9) in the side which is closed by a thin plate, and another (10) in the top through which the record drum may be withdrawn. Lightness of the instrument is secured, as with the kite meteorograph, by the use of aluminum wherever possible.

Meteorographs, both kite and balloon, are carefully calibrated in the testing laboratory, and in addition check observations made in the shelter at the beginning and end of flights, as before mentioned, to determine the base lines. Of course some considerable time may elapse before balloon records can be examined. After their return by the finder, the blackened aluminum sheets upon which the traces have been made are fixed with a preparation of shellac and alcohol. The time lines are then drawn and the vertical ordinates of the three curves read off with a transparent scale, and the values plotted on cross-section paper.

Small balloons released into the air without carrying recording apparatus, flights of which are observed by means of theodolites, are called pilot balloons, as distinguished from sounding balloons. Both balloons are made of pure gum rubber, without seams and spherical in shape. Two sizes of pilot balloons are used, 6 and 9 inches in diameter respectively, uninflated. In pilot-balloon work two methods of inflation are employed, termed "indefinite" and "definite." With the former the balloon is filled to a suitable size and its ascensional rate computed mathematically, or interpolated from a table; with definite inflation the balloon is inflated to produce a lift which will result in a certain desired ascensional rate. This can only be accomplished by the use of a filling apparatus such as is illustrated in Fig. 76.

4. Balloon-Filling Apparatus

Referring to the figure, hydrogen from tank (1) flows under pressure to the three-way cock (2), which, when opened, permits the gas to pass through tubing (3), to the filler-nozzle (4) which fits the mouth of the balloon.

The ascensional rate, e.g., 200 meters per minute, having been determined upon, the balloon after preliminary kneading, etc., to render it pliable, is weighed on the trip scale (5). For the desired ascensional rate mentioned, the free lift of a balloon weighing for instance 34 grams must be 188.0 grams. The latter weight is placed in pan (6) below the balloon, and the balloon filled until it pulls the balance beam upward. Then the flow of gas from the tank is stopped by cock (2), and the balance brought into equilibrium by allowing a little of the gas to escape into the air. The balloon is then sealed and its dimensions taken. Fig. 77 shows the beginning of a pilot balloon flight.

FIG. 76 *Balloon-filling apparatus.*

The flights of both pilot and sounding balloons are observed with one or two theodolites; with the former they are essential, while in sounding-balloon ascensions theodolite readings are used to check heights computed from the meteorograph record so far as practicable, and to determine the direction and velocity of the wind while the balloon

is visible. From theodolite observations (angles of azimuth and elevation) of pilot balloons, made at frequent, successive intervals of time, e.g., one minute, wind directions and velocities are determined by computation and graphical methods at the several elevations above ground reached by the balloon.

FIG. 77 *Beginning of flight of pilot balloon.*

5. THEODOLITES

Among the interesting devices and apparatus adapted or specially designed for balloon and kite flights, the theodolite shown in Figs. 78 and 79 should be mentioned.

The original of the instrument was designed by J. and A. Bosch, Germany, early in the present century, and introduced into the Weather Bureau in 1907. They were in use without alteration until 1917, when the war needs and the resulting expansion of the aerological work, resulted in a redesign of the instrument to make it more rugged; the elements of construction, however, remained unchanged. The instrument differs principally from any good transit in having reflecting prisms mounted within the telescope in such manner as to bend the light rays at an angle of 90 degrees to the axis of the telescope and direct them along the horizontal axis of the eye-piece tube. This arrange-

ment greatly simplifies following the flight of a rapidly-moving kite or balloon.

Referring to the figures, the instrument proper is supported on a substantial white-ash tripod (1), surmounted by a bellmetal casting (2) with sockets for three levelling screws (3). In order to carry the in-

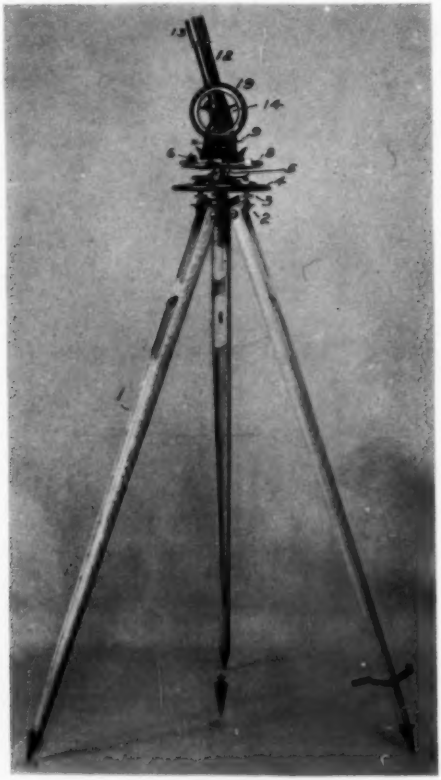


FIG. 78 *Kite and balloon theodolite complete with tripod.*

strument without injury to the delicate parts, handle (4) is used. The vertical axis of the theodolite is at (5), about which the base-plate is rotated after levelling, until oriented with the zero of the horizontal circle at true south. There are two levels, (6) and (7), with axes at right angles, the first on the base plate (8), the second on the telescope standard (9). Portions of the horizontal circle are observed at (10)

and (11) with accompanying verniers by which readings may be made to degrees and hundredths, although tenths are in general sufficiently accurate. The vernier at (11) is added as a convenience to an observer who records readings of azimuth while another operates the theodolite. The telescope tube (12) has its lens in the outer end, protected by a cylindrical sleeve (13) called a sunshade, while the reflecting prisms are placed within the cubical-shaped part (14). The eye-piece is located at (15), focused by rack and pinion operated by knurled-head (16).

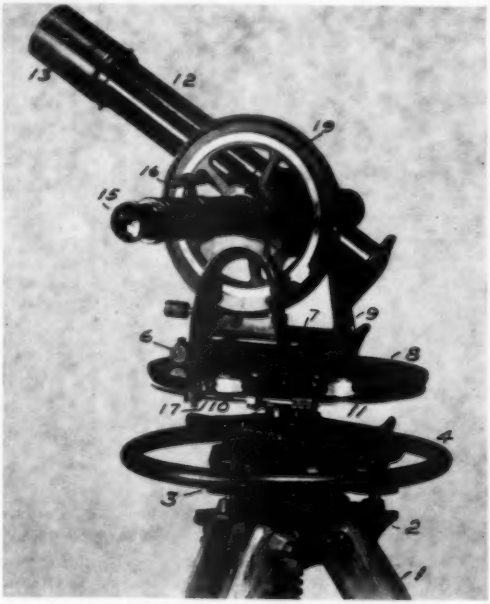


FIG. 79 *Near view of theodolite.*

Both horizontal and vertical motions are made either by a free turning about the axes, or by a slow motion obtained by worm and worm-wheel. The worm, also called tangent screw, for motion in aximuth is seen at (17); that for elevation at (18). Either of them may be meshed or unmeshed with its respective wheel. At (19) is the vertical circle with its vernier. Both the vertical and horizontal tubes are counterbalanced about their respective axes of rotation.

XI. INSTRUMENT SHELTERS OR SCREENS

The shelters described below were designed primarily for temperature-measuring instruments; but they are also suitable for housing hygrographs, and are so used when necessary.

To accurately measure the temperature of the free air at a height of several feet above the earth's surface, the thermometric element must be screened from direct insolation and from heat radiated to and from the element by surrounding objects differing in temperature from that of the free air. This result is practically accomplished by using a box-like screen of wood having a double roof with louvered sides, and a floor

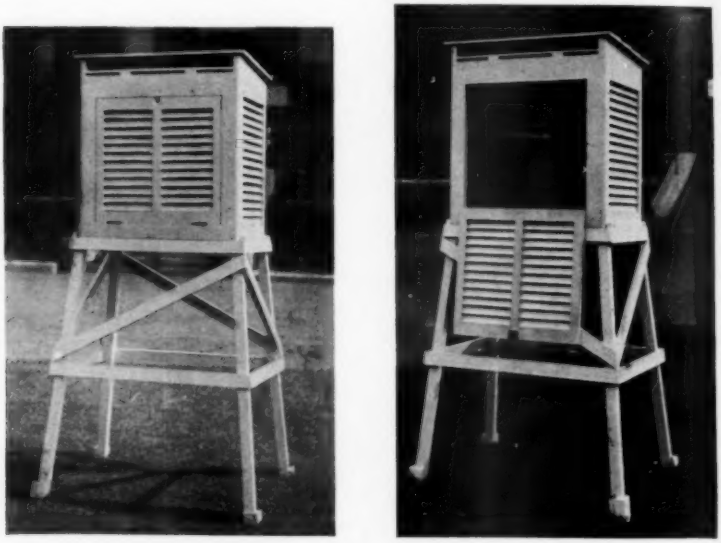


FIG. 80 *Cotton-region shelter mounted on standard support, two views, one showing the maximum and minimum thermometers. (The door is opened only when thermometers are to be read).*

with only enough openings to permit of some air circulation and to dispose of the rain and snow which are occasionally driven in by high winds. The louvered sides at the same time permit a reasonably free movement of the air through the shelter when there is wind, so that the temperature of the air within the shelter is sensibly the same as that without at the same elevation; the most serious difference arises when there is a calm or very light wind accompanied by strong sunshine, no provision being made for artificial ventilation. Also, since the shelter

itself may become hotter or cooler than the adjacent free air, an interchange of heat by radiation is set up between the inner walls of the shelter and the thermometric element. This effect is minimized by keeping the shelter painted as nearly a pure white as possible to secure the greatest degree of reflection. An additional effort to secure accuracy is provided in the large standard shelter by whirling the thermometers, which operation mixes somewhat the air within the shelter.

Thermometer shelters were introduced for meteorological observations early in the 19th century, the names of Glaisher, Stevenson, Stow, Renou, Wild, and others, being associated with their design. Those used by the Weather Bureau at the present time will now be described.

1. SMALL-SIZED SHELTER FOR COOPERATIVE STATIONS

This type of shelter, illustrated in Fig. 80, was developed about 1890 from older forms used in the Signal Service, the principal improvements being the change from a single sloping roof to a double one. All four sides are louvered. The maximum and minimum thermometers are mounted as shown with their bulbs near the center of the shelter, the inside dimensions of which are: length, 27½ in., width, 17½in., and height about 27 in.

When mounted on the standard support, the thermometers are nearly 5½ feet above the ground. The shelter is oriented so that the door faces north or a little east of north.

2. LARGE-SIZED STANDARD SHELTER FOR FIRST-CLASS METEOROLOGICAL STATIONS

This shelter, illustrated in Figs. 81 and 82, is built along the same lines as the one first described, but is made larger to provide room for a whirling apparatus, a thermograph, and, less often, a telethermoscope bulb and hygrograph. The inside dimensions are: length, 3′-1¼″, width, 2′-8½″, and height at center of shelter about 2′-3″.

Since Weather Bureau offices are usually located in cities of considerable size, and it has not as yet been possible to maintain suburban observatories except in a few places, instrument shelters have to be frequently placed on the roofs of office buildings. For such situations the shelter is installed in a steel tower (see page 421), or erected by itself on a steel support, the floor of the shelter being about ten feet above the base of the support, as shown in Fig. 81. This support is also considerably used for ground exposures, but has been superseded since 1922 by the 5-foot support shown in Fig. 82, which of course places the thermometers much nearer the ground, thus making the exposure comparable with that of the small shelter.

FIG. 81 *Standard large-sized shelter on 10-foot steel support*

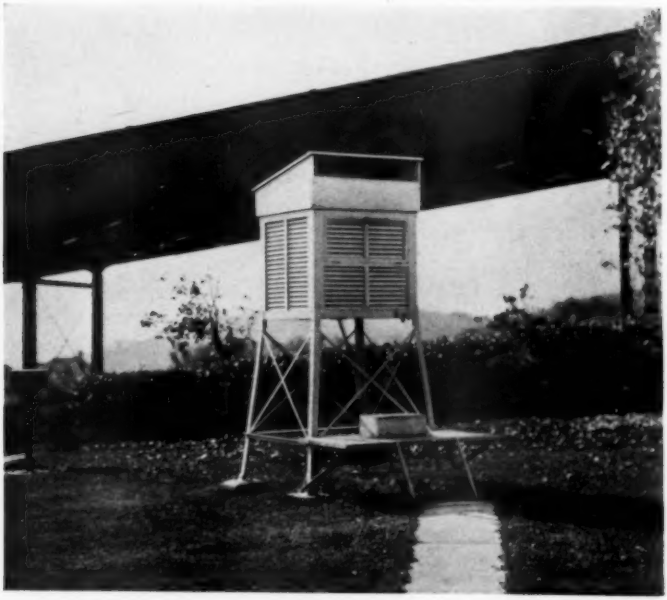


FIG. 82 *Standard large-sized shelter on 5-foot steel support, Duluth, Minn.*

3. Fruit-Region Shelters

The need for a relatively low-priced shelter for special investigations in the fruit regions of the Pacific Coast, led to the design in 1917 of the shelter shown in Fig. 83. The customary louvers are replaced by a double-board construction which cuts off radiation, excepting on the door side, which is covered with wire mesh. Direct sunshine can not reach the instruments, and the error due to radiation through the door is largely if not entirely offset, as developed by tests, by the better air circulation within the shelter. The dimensions are essentially like those of the small standard shelter, and the same support is employed.

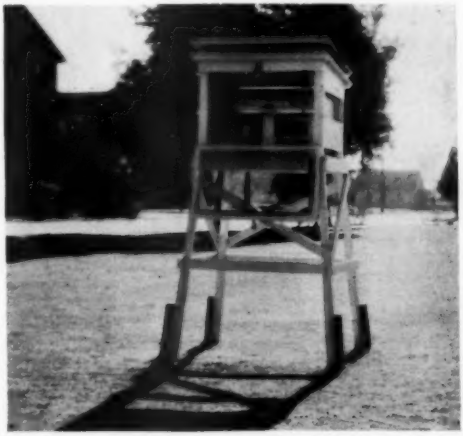


FIG. 83 *Fruit-region shelter on standard wooden support (Door open to show instruments within).*

4. Stevenson Screen

This is the standard shelter of the Meteorological Office of London, and was designed by Thomas Stevenson in 1866. It is smaller than those above described, being 18 in., long, 11 in., wide, and 15 in., high, inside dimensions, and a number of them have been conveniently employed for separately housing the bulb of the Friez distance-recording thermograph. (See page 312)

As seen in Fig. 84, there is the usual double roof; the sides appear similar, but there are double louvers, one set sloping inward and downward, the other outward and downward, so that rain is quite effectually excluded. When thermometers are exposed in this shelter, their bulbs are about 4 feet above ground.

5. KIOSKS

Though sometimes called "street" instrument shelters, these structures are but poorly adapted to the purpose meteorologically, since they are almost entirely constructed of massive iron castings which vigorously absorb and conduct heat under direct insolation. This construction, generally coupled with a poor circulation of air through an interior chamber in the center of the shelter, within which the thermal and humidity elements are exposed, often results in indicated summer day-time temperatures considerably above those of the free air at the same height above ground. The kiosk also houses a tipping-bucket indicating or dial rain gage, (see page 338), which is reasonably accurate.

FIG. 84 *Stevenson screen.*

The kiosk serves mainly as a housing for an interesting instrument and chart display made for the benefit of the public, and it possesses considerable value from that standpoint. The shelter is about 4 feet square at the base, and stands nearly 8 feet high above the concrete or stone foundation. The rain-gage collector, 15 in. square, is at the center of the top, and the water is conducted thence to the tipping-bucket near the center of the glass-covered instrument panel, the side nearest in the picture. Other instruments to be seen are the thermograph at the bottom, the exposed thermometer at the right center, the

Sixe's maximum and minimum to the left, and a hair hygrometer at the top. An aneroid barometer is also quite frequently added.

The kiosk was designed in 1907 and 1908 under the direction of Prof. C. F. Marvin, and was patterned largely after similar street shelters used for many years in Europe. Nearly thirty-five of them are in service in the United States.

FIG. 85 *Kiosk.*

XII. INSTRUMENTS FOR MEASURING AND RECORDING RIVER STAGES

The River and Flood Service constitutes a very important part of the activities of the bureau in safeguarding life and property, in minimizing by its forecasts of flood stages the danger and damage

resulting from floods, especially along the big rivers in the interior of the country. Forecasts of prospective stages furnish information oftimes of great value to navigation, and to those dependent upon streams for water supply in irrigation, the operation of hydro-electric plants, movable dams, etc. It is a service nearly as old as the bureau itself, dating from the early seventies, although the present organization and methods are mostly a development since 1893.

The forecasting of river stages, particularly of flood stages, requires accurate daily synchronous readings of the stage of the river at suitably selected stations upstream from the place for which the forecast is to be made, and, almost always in addition, measurements of the amount and distribution of the rainfall, coupled with a knowledge or estimate of the losses which affect the volume and rate of runoff. Eight-inch rain and snow gages, described on page 333, are employed almost universally for the precipitation measurements; the instruments and apparatus for measuring or recording the height of the water above a predetermined zero stage, are described below.

Briefly, the forecasting of river stages is based upon empirical rules developed for each stream from a study of the relation of river-gage readings at the several stations along its course; the depth, rate of fall, and distribution of the precipitation over its watershed with their relation to the quantity and rate of runoff as affected by soil conditions, weather, stage of water in the stream at the time of observation, etc., all the foregoing, and in addition a knowledge of the capacity of the river channel for runoff, and the effect on the stage of overflows to land adjacent to the channel.

Instruments for measuring river stages fall into two classes, nonrecording and recording. In the former class the bureau employs vertical and inclined staff gages, also chain and weight gages; for recording purposes the Friez and Marvin registers are used, and to some extent the Gurley and Steven's gages in cooperation with the Geological Survey.

All the river gages employed by the bureau measure the vertical height of the water in feet and tenths from its surface to a zero stage estimated to be the bottom of *flowing* water in the stream.

NON-RECORDING GAGES

1. STAFF GAGES

(a) *Vertical staff gages* illustrated in Fig. 86 are constructed of 2 by 12 inches pine or oak, the front, ends and sides dressed smooth. The

overall length must be sufficient to include the range of river stages expected, with a margin for abnormal high or low water. Two methods are used in graduating the gage: one is to paint it on the front side, the other and better way, to attach sectional enamelled-iron scales of convenient length, the numbers designating the foot marks on separate plates. A gage of the latter type has the advantage over the painted staff in being more durable when well enamelled, and dirt is easily removed by washing.

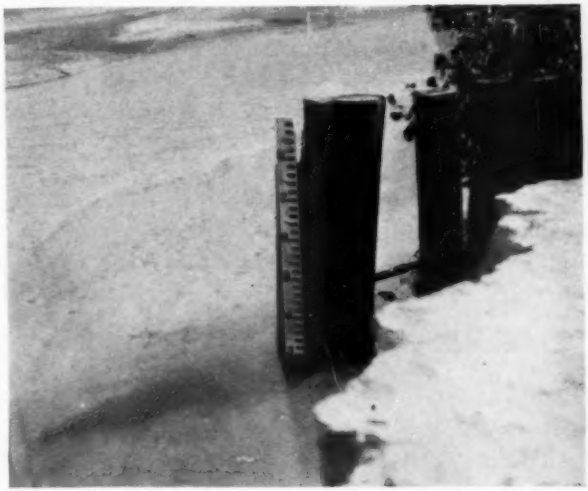


FIG. 86 *Vertical staff gage.*

The painted staffs are given two coats of white lead. Then the graduations are chiselled or burnt into the front surface of the board and filled with black paint, as are also the 6-inch figures designating the feet. The enamelled scales are 4 inches wide and have the tenths of feet painted on them in small black figures.

Vertical staff gages are securely attached to a permanent support, such as a bridge pier, abutment, or quay, where the whole range of gages may be measured.

Occasionally it is possible to cut a gage into the masonry face of a bridge pier. The same general scheme of graduations and lettering above described is used, except that white graduations and letters are painted against a black asphaltum background.

(b) *Inclined staff gages* are required where it is not practicable to use a vertical staff because of the absence of a support, at least for a gage to measure the low-water stages, which condition neccessitates laying the staff down the bank of the stream, following the profile in a general way, as illustrated in Fig. 87. Instead of a 12-inch board for the staff, oak, pine or cypress timber 6 inches square is quite frequently employed, usually firmly bolted to substantial wooden posts driven vertically nearly 6 feet deep into the bank at intervals of about 6 feet. The staff proper is partly imbedded in the bank, only $1\frac{1}{2}$ inches or so being exposed. To the dressed upper face of the staff $\frac{1}{4}$ by 2 inches strap iron is screwed which is graduated in place in feet and tenths to correspond to measurements made in the vertical. The figures, 4 inches high, are sometimes burnt into the staff alongside the iron scale, and both graduations and figures painted black against a white background. The present tendency is to use more durable materials, both for vertical and inclined gages, the entire gage being constructed of concrete as described below, or the support at least of the inclined gage made of concrete as shown in Fig. 87.

FIG. 87 *Vertical and inclined staff gages. (Picture taken by the Geological Survey)*

At a number of stations on the Ohio and Mississippi Rivers inclined gages have been built of concrete laid in a trough at least 12 inches in width and 24 inches in depth, with supporting anchors or wings of similar cross-section extending about two feet on each side at intervals of not more than 10 feet. The graduations and figures of ample size are impressed into the concrete surface when it is fresh, the figures preferably being placed so that the gage may be easily read from the bank of the stream. The depressions forming the graduations and figures are afterward filled in with a rich cement mortar, colored either black or brown. The figures, when single integers, should be placed on the left side of the gage looking toward the water, and along the center of the

entire length inverted T-rails or soft iron plates, about 4 inches in width and ¼ in., in thickness, should be laid and bolted in such position that when the concrete is poured the surface of the rail or iron plate will be flush with the face of the concrete. In cases where double figures are used in a gage only 12 inches in width, one figure must be placed on each side of the center plate.

2. CHAIN AND WEIGHT GAGES

This device, illustrated in Fig. 88, is often employed in place of a staff gage where there is a relatively small range of stages. The box (1), shown in the illustration, is about 24 inches long and is attached hori-

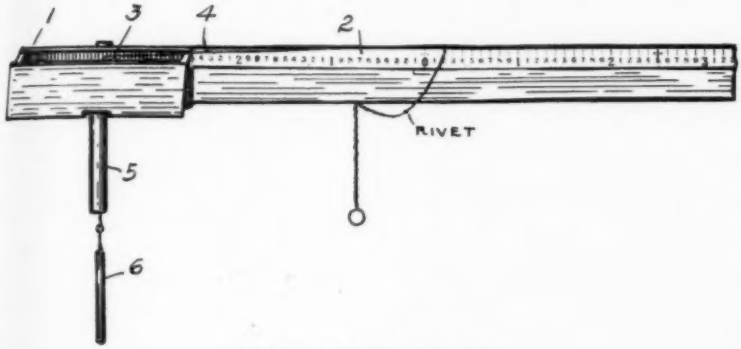


FIG. 88 *Chain and weight gage.*

zontally to the outside of a bridge railing, or sometimes to the side of the bridge proper. The sectional enamelled-steel scale (2), secured to a 1″ by 6″ board, is placed alongside the box, also in a horizontal position. Within the box is a pulley (3) over which the chain (4) passes from the box through pipe or downspout (5). To make a reading with the gage, the cast-iron weight (6) is allowed to drop until its lower end just touches the water. A reading of the scale with reference to a rivet, or index mark set into the chain near the right-hand end, gives the stage, the zero of the stage having been previously determined. After reading, the weight and chain are locked in the box for safe keeping.

RECORDING GAGES

In addition to the large number of river gages which require direct reading, a considerable number of the Weather Bureau stations along the important rivers are equipped with recording or indicating registers. Besides the advantage of maintaining a continuous record of the river

stages for stream-flow and flood-forecasting studies, these instruments are of particular value at the larger stations, since the height of the water can be furnished at a moment's notice in answer to inquiries, often urgent, received by telephone or otherwise.

There are two principal types of registers in use in the bureau, namely, the Marvin and the Friez, of which the Marvin gage is em-

FIG. 89 *Float and counterweight pipes on pier of bridge, Cincinnati, O.*

ployed considerably more frequently than the others. However, the installation of float and counterweight pipes is practically the same for any installation. A float pipe is essentially a stillwell to which the river water has limited access at the bottom, usually through lateral inlet pipes placed somewhat below zero stage. Float pipes, located if

possible where wave action in the river is the least, may be attached to the outside of a bridge pier, as illustrated in Fig. 89, or better still installed within the bridge pier while it is in course of construction. A copper float, usually 6 inches in diameter, rests on the surface of the water in an 8-inch, or sometimes larger, standard wrought-iron flanged pipe, the float being suspended by a perforated bronze tape passing over a sprocket wheel in the transmitter, or the register in the Friez gage. The pull of the float and tape is counter-balanced by a weight free to move in a $1\frac{1}{4}$ inch pipe parallel to the float pipe and close alongside. Vertical motion of the water in the float pipe is thus communi-

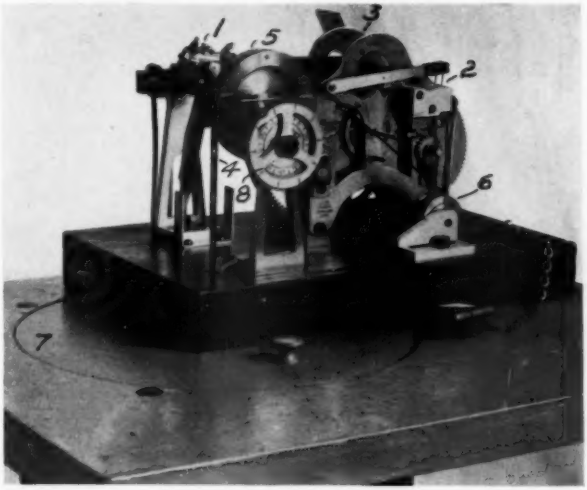


FIG. 90 *Marvin transmitter.*

cated to the instrument attached to the top of the float pipe, where an electrical circuit is completed to the indicator for each rise or fall of a tenth of a foot, or the record is made direct when a distance-recording device is not desired.

3. MARVIN WATER-STAGE REGISTER

The Marvin register, named after the inventor, Prof. C. F. Marvin, was introduced in 1904. It is composed of two principal parts: One, (a), the float mechanism or transmitter, located at the river; the other, the indicator, (b), installed in the distant office and connected electrically with the transmitter.

The *transmitter*, (a), consists essentially of a contact-making device which responds to changes in level of the water in the float pipe. Referring to Fig. 90, (1) is a two-way mercury switch which selects the wires for the current flow in a three-wire circuit, while (2) is a second switch actuated by the governed clock mechanism, (3), which serves to determine the duration of contact, and, as a result the positiveness of the action of the electromagnets of the indicator or recorder. A perforated bronze tape, (4), is passed over the sprocket wheel, (5), and thence to the wheel (6). The end of the tape below wheel (6) carries a counterweight, while at the other end of the tape is a 6-inch copper float which

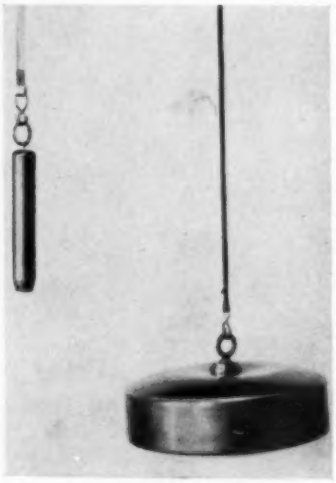


FIG. 91 *Float and counterweight.*

rests on the surface of the water in the float pipe. The float and counterweight are shown separately in Fig. 91. Changes in the height of the water cause the sprocket wheel (5) to rotate, which rotation in turn tilts the mercury switch, (1), and releases the clockwork (3). The electric circuit is thus closed by switch, (2), for each tenth of a foot of change of water level and the rising or falling magnet of the indicator energized selectively through a 3-wire circuit, illustrated in Fig. 92, which produces in turn the motion of the indicator-hand over the dial. A removable iron plate, (7), closes the top of the float pipe. This plate keeps much moisture from reaching the transmitter, and also prevents small articles from dropping into the float pipe.

At (8), Fig. 90, there is a pair of dials similar to those used in the anemometer, which when properly set shows the exact stage of the river.

When the transmitter is exposed to the weather, it is protected by two copper covers, an inside one that covers the instrument proper, and a larger outside cover hinged to the base plate and locked to the plate with a padlock. When placed in a recess in a pier, the outer cover is omitted.

FIG. 92 (a) *Marvin indicator, front view.*

(b) *Indicator*,—This portion of the register is illustrated in Figs. 92 (a) and (b). It consists essentially of two pairs of electro-magnets, one pair for rising and one for falling stages of the river, (1) and (2) respectively in Fig. 92 (b). When either of these pairs of magnets is energized, it produces the desired rotation of the hand over the indicator dial through intermediate gear wheels, the first of which (3) is turned by a pivoted two-way ratchet (4) controlled by the armature (5), which takes a position midway between the poles of the magnets when current is not flowing, but which is pulled to one side or the other when the

magnet is energized. The bell cranks (6) controlled by adjustable coiled springs (7) maintain the neutral position of the armature.

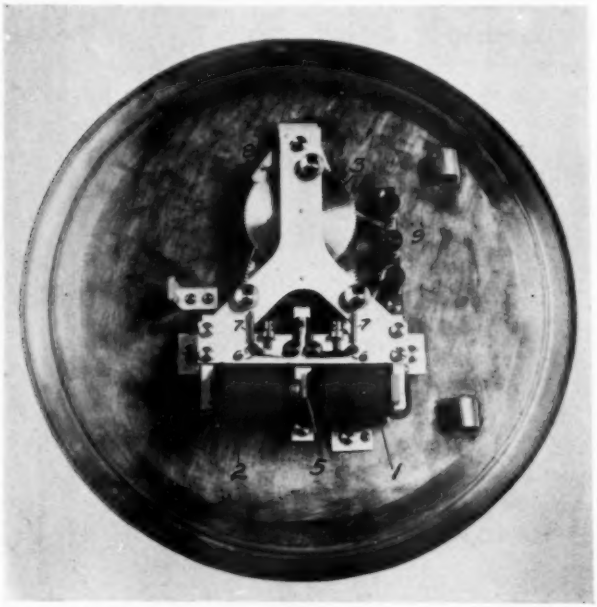


FIG. 92 (b) *Marvin indicator, near view, cover removed to show mechanism.*

The step-by-step rotation of wheel (3) is effected by latch (8). The binding posts for the electrical connections are at (9), which are also

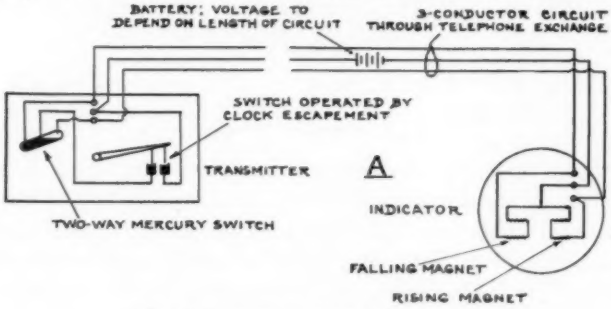


FIG. 93 *Diagram of circuits, Marvin register.*

shown on the diagram of circuits, Fig. 93. The arrow point on the face of the dial shows at any time whether the river is rising or falling. When the point is down, the river is falling, and vice versa.

(c) *Recorder*,—At a few river stations the indicator has been replaced by a recorder of the kind shown in Fig. 94, originally built by Jules Richard, France, as a tele-thermograph recorder. It is operated on a three-way circuit in a similar manner to the indicator. The motion of the pen-arm is produced through the medium of clock work in the case (1), which operates to turn gear wheel (2) clockwise or anti-clockwise for rising and falling stages respectively. Sector (3) and the pen-arm (4) receive motion from a small pinion on the axis carrying the wheel (2). The record cylinder is the same as that used on the long-range thermograph.

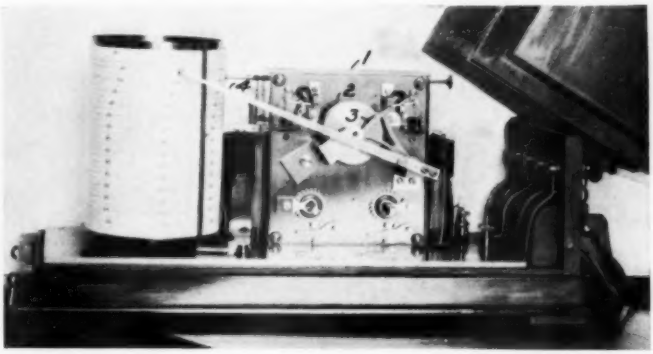


FIG. 94 *Recorder for use with Marvin transmitter.*

4. FRIEZ WATER-STAGE REGISTER

This register was patented in 1901 by Julien P. Friez and Sons, and a number of them have been satisfactorily employed, both in recording river stages, and in connection with the exacting requirements in the forest stream-flow experiments at Wagon Wheel Gap, Colo.

Since the gage does not transmit stages to a distant recorder, the complete recording mechanism is installed at the top of the float pipe, which, because of the employment of a 7-inch copper float should be at least 9 inches in diameter inside.

Referring to Fig. 95, a perforated phosphor-bronze tape carrying the float and counterweight rotates the sprocket wheel (1), on the axis of which is a small pinion (2) which imparts motion to the gear (3) on an extension of the shaft of the recording drum (4). To fit the record sheet of the instrument to the various ranges of river stages found at different places, a number of sizes of sprockets and gears are used, by means of

which the ratio of the length of one revolution of the drum, 12 inches, to the rise or fall of the water in the stream, may be varied from 1:1 to 1:20. The clock (5) at the left of the drum moves the pen-carriage (6) from left to right through the medium of screw (7). Ordinarily a seven-day record is used, but if a more open time scale is desirable, a one-day record is provided. The record is 7½ inches wide; the cast-iron base of the instrument (8) is 10 in. by 20 in.

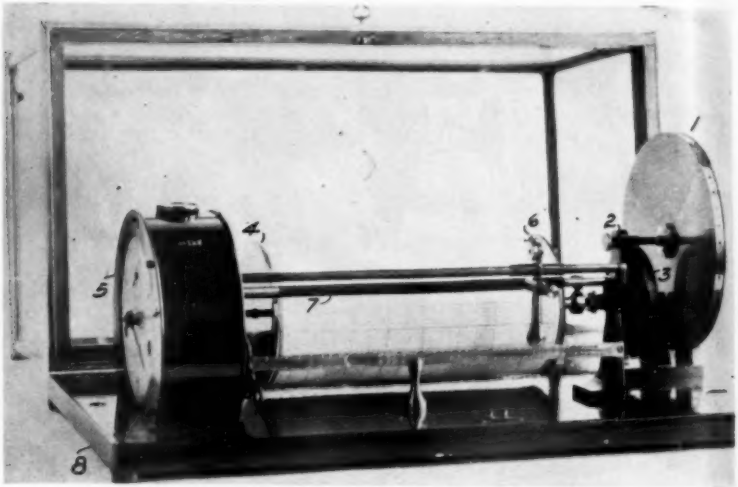


FIG. 95 *Friez water-stage recorder.*

XIII. INSTRUMENTS AND APPARATUS FOR MEASURING THE DEPTH AND WATER CONTENT OF SNOWFALL

Snow-depth measurements are made by the bureau with the following principal objects:

(1) To determine the snowfall since last observation once or twice daily for climatological records of precipitation; (2), to measure daily at a regular time the accumulated depth of snow on the ground without regard to its density; and (3), to measure the accumulated depth on the ground so as to compute the density of the snow when the water content of the snow layer has also been measured. (1) and (2) serve the needs of meteorology; (3) furnishes information of special value to irrigation and hydro-electric interests, and others largely dependent on winter snowfall for summer water supply.

Direct measurements of the water content of freshly fallen snow are necessary to accurately determine the precipitation, and such measurements are generally made at the same time as the daily observations of snowfall depth mentioned in (1) above. To multiply the observed depth of snowfall by an assumed constant snow density of .10, to obtain the amount of precipitation in terms of melted snow, often leads to a large error in individual observations, although the use of .10 may give good average results in many cases. The density, however, is known to range through wide limits.

As mentioned under (3) above, the water content of a snow layer must be known in conjunction with the depth of the layer before the density can be computed. When many such measurements of water content are made, as in the mountain regions of the far west where extensive surveys of the snow on the ground in the spring are undertaken with the object of estimating the runoff of a watershed, apparatus has been introduced by means of which the depth and water content of a snow layer are found in one operation, as described later under "Snow-sampling tube and balance." The water content in inches of a snow sample divided by the depth of the snow layer, also in inches, gives the density of the snow as a percentage of that of water, volume for volume.

SCALES FOR MEASURING SNOW DEPTH

Any well-graduated substantial scale is suitable, preferably graduated in inches and tenths, for the measurement of the ordinary depths found in daily observations. Most of the first-class stations, however, are equipped with a stick 36 in. long, and 1 in. by 3/8-inch in section, its ends protected by brass ferules. The rain gage measuring stick is also used. Snow-sampling tubes (Fig. 97) have a graduated steel tape riveted to them for use in depth measurements.

To facilitate the measurement of the depth of freshly fallen snow, snow mats, so-called, may be conveniently employed. They are made of white duck 28 in. square with triangular pockets at the corners to receive strips of wood, $2\frac{1}{4}''$ by $\frac{1}{4}''$, used as diagonal braces to deep the mat taut and flat. The mat is laid on the snow already on the ground and forms a suitable surface from which measurements can be made with a stick. A cord should extend from the mat to a nearby stick for use in locating the snow-covered mat and to prevent its being disturbed.

Aside from the 36-inch snow stick, the following-described device is the only one designed for depth measurements alone:

1. SNOW STAKES

These stakes are used quite extensively where deep snowfall occurs, particularly in the western mountains, frequently in conjunction with snow surveys. The first stakes employed in the bureau were made in one piece, of 1″ by 6″ lumber, and designed by Prof. C. F. Marvin. Stakes of smaller cross-sectional area, however, were found to reduce errors due to radiant heat and the eddying of the snow about the stick, so that in 1913 a new model was introduced, the construction being practically the same as now employed, excepting that the sticks were in one piece, while in the present form adopted in 1916, the stick is made in sections, three of which are required for a scale length of 90

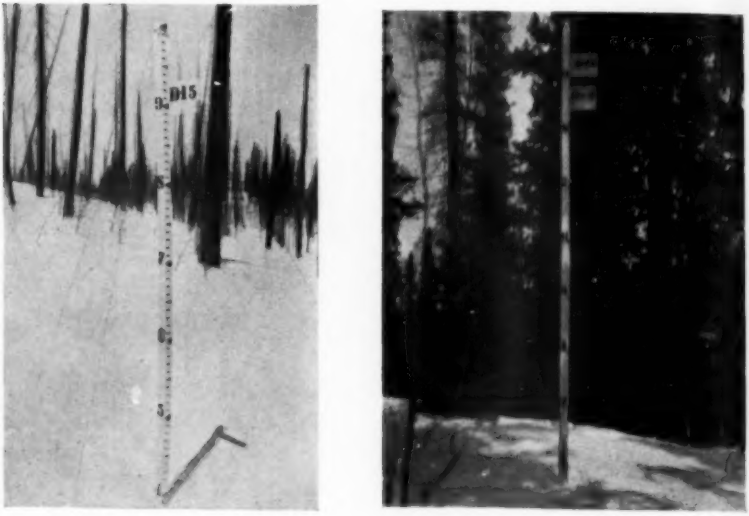


FIG. 96 *Snow stake.*

inches. Sticks longer than 90 inches are assembled by adding intermediate sections, the standard lengths issued to meet varying conditions being 90, 120 and 150 inches.

The stake illustrated in Fig. 96 is made of 1¼-inch cypress, bolted to a galvanized-iron angle, the end pointed so that it may be readily driven into the ground. To hold the stake rigidly in a vertical position, three galvanized-iron guy wires (No. 16 B.W.G.) are generally required. Enamelled-iron scales with brass numbers have been used considerably. As an alternative to the metal scales and numbers, the

graduations and numbers have also been stencilled on to the stick in black paint against a white background. The numbers 1, 2, 3, etc., designate 10, 20, 30, etc., inches of snow respectively.

APPARATUS FOR MEASURING THE WATER EQUIVALENT OF SNOW

A tube of any reasonable dimensions may be quite conveniently used to determine the water content of a snow layer of moderate depth. The overflow can of the 8-inch rain gage Fig. 26(2) is an example. A section of the snow layer is cut out by pushing the open mouth of the can to the bottom of the layer, the snow being retained in the can by means of a thin sheet of metal or wood while the can is being lifted and inverted. The snow is then melted, preferably by adding a known quantity of warm water. Then the depth of the whole amount is measured in hundredths of an inch in the brass measuring tube of the 8-inch gage, and the depth of the water used to melt the snow subtracted to get the water content of the snow.

The snow-sampling tube and balance described below permit of a more convenient method of measurement, especially where deep snow layers are surveyed over extensive areas in the spring, such as are found in the Sierra Nevada and Rocky Mountains.

2. SNOW-SAMPLING TUBE AND BALANCE

The method of sampling snow with a tube and finding the water content by weighing, was first introduced by Robert E. Horton, Utica, N. Y., in 1904, and later the idea was utilized by Dr. H. F. Frankenfield and embodied in apparatus designed by Prof. C. F. Marvin, the first appearing in 1910 and the second in 1913. The type shown in Fig. 97 was introduced in 1916, an improved cutter made of steel, (1), being used, and sheradized steel tubing, (2), substituted for galvanized down spouting. The cutter has an inside diameter of 2.66 inches, while the inside diameter of the 3-inch steel tubing is 2.94 inches, so that when the snow layer is sampled, the core of snow passes up into the tube freely, and is usually held quite firmly, although occasionally, when the snow is dry and loose in texture, some tamping is required to prevent its dropping out. Fig. 97 also indicates the manner of using the sampler. The tube and its snow contents are suspended from the balance (3) carried on the hook of the alpenstock (4). The latter is plunged firmly into the snow to form a convenient support for the apparatus. Since the diameter of the cutter and the weight of water per unit volume are

known, the scale of the balance has been graduated to read direct in inches and tenths of water equivalent. One-fifth of a pound of snow is equal to one inch of water for this particular arrangement.

Since snow surveys require that the equipment be carried and measurements made over extensive areas, often rugged in character, it is essential that the apparatus be light in weight. The balance has therefore been made of aluminum where possible, and the tube itself has thin walls.

FIG. 97 *Snow-sampling tube and balance.*

XIV. WIND-INSTRUMENT SUPPORTS AND TOWERS

The necessity of exposing wind instruments, so as to raise them high enough to provide a so-called "free" exposure, and at the same time permit of their being conveniently reached for oiling, cleaning, and other needed attention, has led to the use of the standard equipment described below.

Where it is unnecessary to go very high to be free from the interference of objects on the roof of a building, which obstruct the wind and cause eddies, it is customary to use a pipe support having an overall height of about 18 feet, but occasionally to reach a greater elevation one of 26 feet is employed. Any height in excess of the latter figure, however, requires a more stable form of support, which is found in a four-legged steel tower of light construction. At stations of the second class,

where a non-recording wind vane and an anemometer connected to a distant register or indicator are exposed on the roof of a builting or upon some other suitable structure, a pipe support with a height of only seven feet is used. Advantage in this case must be taken of some elevated part of the building itself.

1. PIPE SUPPORTS FOR WIND VANE AND ANEMOMETER

(a) *18-foot support*,—The type first used, and employed quite frequently at present, is shown in Fig. 98. Pieces of two-inch standard

FIG. 98 (a) *Standard 18-foot wind-vane and anemometer support at Lander, Wyo., also large-sized shelter on steel support, and overflow can of 8-inch rain and snow gage used as collector for snow fall.*

pipe form the body of the support, one piece 4 feet long extending from the 12-inch cast-iron base plate (1) to the wind-vane contact box (2), and a second piece nearly 12 feet long, from the contact box to the point

of attachment of the anemometer cross-arm (3). One and one-half-inch pipe makes up the balance of the upright. A 6-foot vane (4) is carried on roller bearings at (5), and an extension of the vane rod formed of 1/8-inch iron pipe extends downward to the contact box which contains contacts of the kind described on page 000. The base of the support is secured with lag screws to a wooden platform as shown, and held rigidly in a vertical position by means of three iron-rod guys with turnbuckles. The wind-direction points (6) are now considered unnecessary.

This support in a slightly different form from that illustrated appeared first about 1893. Certain modifications were made by 1907,

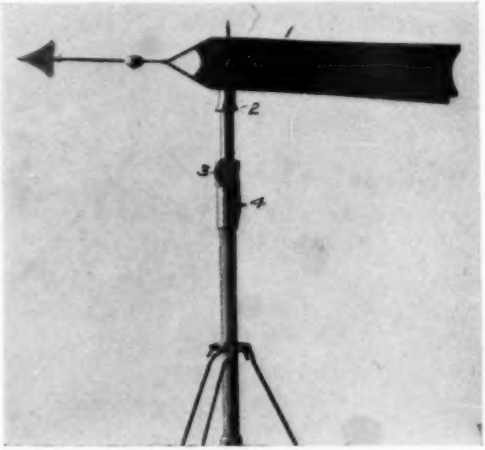


FIG. 98 (b) *Upper portion of 18-foot support, showing 4-foot vane and Fergusson wind-vane bearing.*

when the 4-foot ball-bearing wind vane with contacts (all included in the same assembly) was introduced, the iron contact box (2) and the inside pipe being omitted. This type of support is shown in Fig. 99. The standard support and equipment at the present time is the same as that illustrated in Fig. 98(a), excepting for the use of a 4-foot vane with the Fergusson bearings in place of a 6-foot vane and roller bearings. The upper portion of the support is then as shown in Fig. 98 (b).

Figs. 98 (a) and 99 show typical roof installations of meteorological instruments, including the shelter mounted on its steel support, and

the precipitation gages. In Fig. 98 (a) the overflow can of the 8-inch gage is exposed for catching snow. Fig. 99 shows the sunshine recorder mounted on the roof of the instrument shelter, and the 8 and 12-inch precipitation gages nearby on an extension of the walk laid on the roof of the building.

FIG. 99 *18-foot wind vane and anemometer support at St. Louis, Mo.; also precipitation gages and instrument shelter on steel support.*

FIG. 100 *7-foot wind-vane and anemometer support at a special meteorological station in the West Indies.*

(b) *26-foot support*,—The construction of this support is similar to the one previously described, excepting that the anemometer is placed above the 6-foot vane as a rule to get the maximum elevation, the wires to complete the electrical circuits to the anemometer being threaded through the inside pipe joining the wind vane and the contacts in the box below. Two sets of guy rods are used.

(c) *7-foot support*,—This type of support, illustrated in Fig. 100, was first purchased in 1909 from Julien P. Friez and Sons, with whom it originated. One-inch pipe is used for the body of the support, which is screwed to an 8-inch base plate, and surmounted by a 4-foot wind vane of the kind used on storm-warning towers. (See Fig. 102). Three guy rods are employed, and the anemometer exposed on a cross-arm similar to that found on the large-sized standard support, but of lighter construction.

2. WIND-INSTRUMENT TOWERS

The standard tower, 40 feet high from base to apex, is shown in Fig. 101. It is built of light-weight steel angles bolted together, and braced with 3/8-inch steel rods; all hot galvanized. They were first used in 1901, wind-mill towers being adapted for the purpose. Occasionally the height is changed to 30 or 50 feet to meet particular requirements of exposure, a ten-foot section being respectively omitted or added.

In Fig. 101, the entire out-of-doors instrumental equipment of a first-class station is shown, excepting the nephoscope. The sunshine recorder is attached to the hand-railing, which surmounts the platform at the top of the tower. A short pipe support, extending through the apex of the tower, carries the wind instruments, the base of the support being attached to short angles bolted to the girts about 5 feet below the apex. The wind-vane contact box may be seen slightly above the apex.

XV. STORM-WARNING TOWERS AND LANTERNS

Daily weather forecasts are distributed through the medium of the newspapers, by telegraph, mail, telephone, weather and temperature flag displays, and last, but by no means least, nowadays by radio broadcasting. Forecasts issued for the benefit of navigation of course feature warnings of severe storms, although other phases of the weather are often important.

Early in the history of the bureau means for promptly reaching those interested led to the display of flags by day and lanterns by night at important ports, and other places easily visible from the vessel fairway. Any stout mast was first used for the display, but with the increasing distribution of electricity, a way was opened for much improving the display and at the same time making it more convenient for the displayman, who was obliged either to climb to the lanterns to light them or hoist them from the ground. The latter method is still

required to some extent, but the facilities are much improved. Small oil-burning lanterns were employed for the early mast displays; the present-used lanterns are much larger and stronger and have 12-inch lenses. Improvement in the visibility of the night display by means of large and comparatively heavy lanterns, necessitated a support sufficiently strong to carry them, so that soon after the beginning of the

FIG. 101 *40-foot wind-instrument tower at Lynchburg, Va.; also shelter within tower, sunshine recorder attached to tower handrailing; precipitation gages in left foreground.*

present century, steel towers were introduced, usually 50 feet, but occasionally 85 feet in height from the base to the apex, and surmounted by a steel-pipe flagstaff extending 25 feet farther upward. The system of display stations has since grown until there are nearly 400 along the seacoasts and the shores of the Great Lakes, nearly two-thirds of them being equipped with towers.

Radio is extending the value of the storm warnings by making them available to vessels at sea and others unable to take advantage of the flag and lantern displays. The latter have one obvious advantage, however, that of being continuous, so that he who runs may read, provided he can see.

1. STORM-WARNING TOWERS

(a) *50-foot towers*,—The standard display station is equipped with a tower, nearly always 50 feet in height, with three 12-inch lanterns, usually electric but sometimes oil-burning, and flags for hoisting by day. Fig. 102 illustrates the 50-foot tower and three electric lanterns,

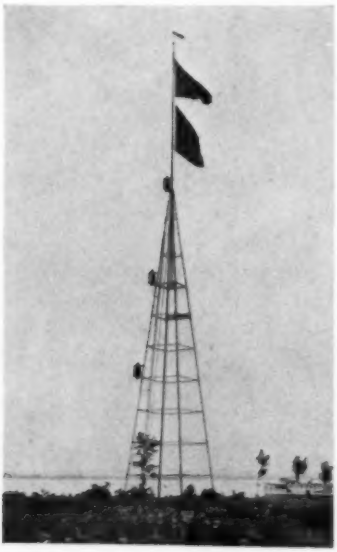


FIG. 102 *50-foot tower, electric lanterns.*

FIG. 103 *85-foot tower, electric lanterns.*

the lighting of the latter being controlled by switches generally placed in a weather-proof cast-iron box attached to the ladder of the tower near its base.

The construction is similar to that of the wind-instrument tower previously described, except for the omission of the platform and hand-railing at the apex, and the inclusion of a steel flagstaff. The latter is made up of three sections of steel pipe, a middle one of 3 inches nominal diameter about 20 feet long, reenforced by steel angles extending

through it lengthwise to resist wind pressure tending to bend the pipe above the apex of the tower; and two pieces of 2½-inch pipe at top and bottom joined to the middle section by dowelled steel joints. The lower section is bolted to a cast-iron base plate carried on two steel angles extending diagonally across the tower. A 4-foot vane, of the type described on page 329, surmounts a cap to the flagstaff, which cap also carries two 3/8-inch halyard pulleys. The lanterns in the installation shown are spaced 15 feet apart, and are clamped to the flagstaff and the corner of the tower so as to lie in a vertical plane. The middle lantern with clear glass lens is lighted with two 46-watt condensed-filament lamps, and, in order that the intensity of light from the white and red lanterns shall be approximately equal, two 94-watt lamps are placed in the lanterns with the red lenses, the top and bottom lanterns of the three. Tests have shown that the spacing of the lanterns must be 4.6 feet in order that the lights may be separated with the naked eye when the observer is one mile distant. When spaced 15 or 20 feet apart, a good glass will separate the lights at distances as great as 10 or 15 miles, depending upon atmospheric conditions.

Various arrangements of the lanterns by night and the flags and pennants by day indicate the direction from which a dangerous storm will blow; no other information is given, excepting, however, that a display of all three lanterns, or of two square flags, red with black centers, indicates the approach of a tropical hurricane, or any exceedingly severe cyclonic disturbance.

(b) *85-foot tower*,—This higher tower, shown in Fig. 103, is used occasionally where the lanterns must be seen from an exceptional distance, or there are trees, buildings, or other objects obstructing the view of the lanterns from the vessel fairway. The construction of necessity is somewhat heavier than that of a 50-foot tower, and a platform and handrailing have been added at the apex; but otherwise there is no essential difference. The weight of the large tower is nearly 5000 pounds, and concrete footings of liberal dimensions are required. The smaller towers are sometimes erected on the roofs of buildings, the footplates being bolted direct to the roof members or to a suitable superstructure, but when placed on the ground concrete footings are nearly always employed.

2. LANTERNS

(a) The *12-inch electric lantern*, illustrated in Fig. 104, has a framework of bronze with hinged doors for access to the lamps and for clean-

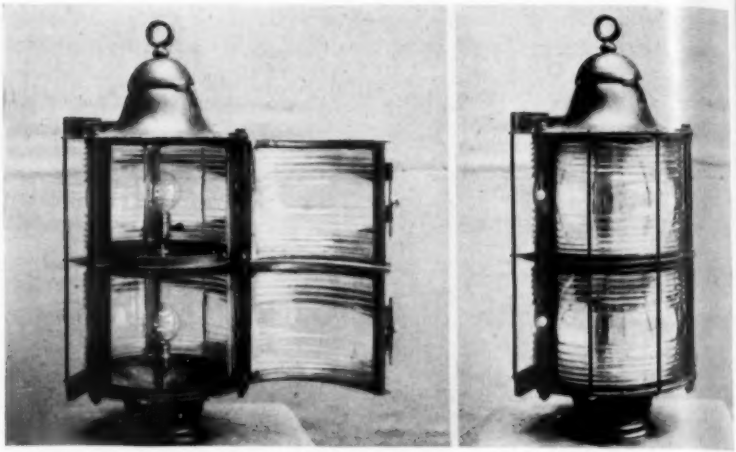


FIG. 104 *12-inch electric lantern.*

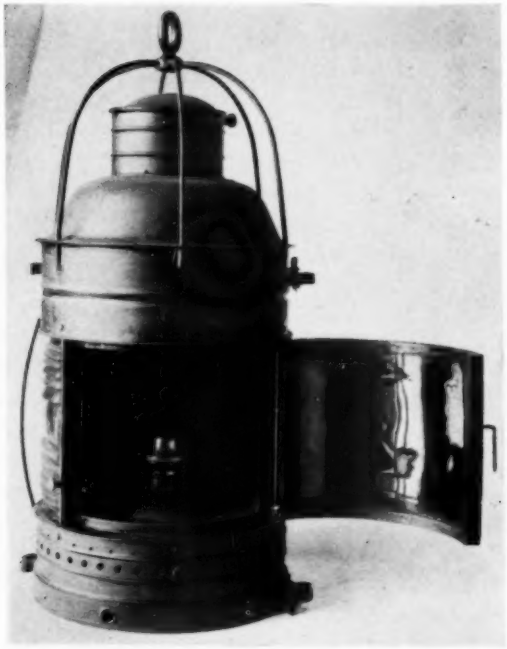


FIG. 105 *12-inch oil-burning lantern, door open.*

ing the lens inside. Ventilation is provided through holes drilled in the base and dome, those in the latter protected by a rain shield. There are two cylindrical Fresnel lenses, each having a 110-volt lamp with its condensed filament carefully focussed in the optical center, both together therefore capable of projecting to all points of the horizon a flat beam of light of considerable intensity, excepting for unavoidable interference due to the tower and to the frame work of the lantern itself.

(b) *12-inch oil-burning lanterns*, Fig. 105, are used where electricity is not available. The body of pressed steel carries one cylindrical Fresnel lens. Light is provided by a single, flat-wick lamp, so positioned as to place the flame approximately in the center of the lens. One of the three sections of the lens forms part of a hinged door giving access to the interior of the lantern. Adjustable ventilation is provided through the base of the lantern by means of a brass ring containing holes. When the ring is slipped around one way or the other a second row of holes leading to the air space about the base of the lamp, is more or less exposed as desired.

The hoisting of these lanterns, which weigh about 60 pounds apiece, is accomplished with a winch or hoisting drum of stout construction attached to the tower ladder near the base. A yard arm clamped to the flagstaff above the tower apex, carries a 12-inch pulley near its outer end, over which passes a 5/16-inch galvanized-steel hoisting cable, one end carrying the lantern or lanterns, the other extending to the hoisting drum. To a cross bar, also at the outer end of the yard arm, two 3/8-inch steel cables to guide the lanterns when they are being hoisted or lowered, are clamped, the lower ends secured to turnbuckles terminating in hooks attached to the girts near the base of the tower. The cables are passed through rings on each side of the lantern at top and bottom. Short lengths of cable accompanied by suitable fittings are used to join one lantern to another and give the proper spacing when two or three lanterns are hoisted.

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Humidity Recorders.—After calling attention to the fact that the intelligent design of telephone switchboard equipment requires a knowledge of the atmospheric conditions under which such equipment is to operate and that the Weather Bureau records apply to outdoor conditions only, the paper describes various instruments constructed to obtain such information automatically. In the first method discussed two matched mercury thermometers are used to determine the wet and dry bulb temperatures and these temperatures are recorded by photographing the thermometers at regular intervals. Although capable of accurate results this arrangement suffered from obvious inconveniences and was soon replaced by two resistance thermometers connected to a self-balancing Wheatstone Bridge which alternately recorded the two temperatures.

The significant information is apparently the relative humidity and although this quantity can be computed from records obtained by either of the two methods already described it was found desirable to construct an instrument which recorded relative humidity directly. It was noticed that if lines of constant humidity be plotted with wet and dry bulb temperatures as the coordinates, these lines very conveniently turn out to be straight and to have a common point of intersection at about (7°F, 7°F). This convenient relationship made possible the construction of a very satisfactory direct reading recorder.

Resistance thermometers are used to determine the wet and dry bulb temperatures and the self-balancing recorder to which these are connected introduces into a Wheatstone Bridge resistances proportional to the amount the wet and dry bulb thermometers respectively are above 7°F. In balancing this last bridge the recorder moves a contact and the attached pen to a position which depends on the ratio of the two inserted resistances and therefore on the humidity so that the scale can be marked directly in per cent. The machine also simultaneous'y records the dry bulb temperature. Photographs of records gotten with the machine show very distinctly the difference between indoor and outdoor conditions, the effect of opening the window and the closeness of control in a constant humidity chamber. [E. B. Wheeler, Bell System Technical Journal, *3*, pp. 238-258; April, 1924.]

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